January 2007

UBS research focus

Climate change: beyond whether

Link to human activities now virtually certain
Effects extend far beyond global warming

Policies to regulate emissions will strengthen
Despite this, greenhouse gas concentrations to increase

Creates investment risks and opportunities
Focus on renewable energy and energy efficiency

UBS Wealth Management

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Dear reader,

Most of us have experienced what global warming feels like firsthand. After all, four of the five hottest years in the past hundred years occurred between 2002 and 2005. These periodic changes that we observe in seasonal weather patterns are no longer anecdotal. The earth is warming, and the secondary effects of global warming, such as thinning sea ice, rising sea levels, retreating glaciers, and changing precipitation patterns, are accelerating. In the context of longer-term trends, they represent evidence of widespread climate change.

This presents us and future generations with many humanitarian and ecological concerns. Since these issues have been explored to great extent elsewhere, it is not our intention to retrace such well-trodden ground. However, the consequences of, and our reaction to, climate change will significantly alter the outlook for many of our investment decisions. In reviewing the implications of the latest scientific research through the lens of UBS's investment research, we believe that the following pages offer a level of analysis of these risks and opportunities that has not hitherto been available anywhere.

The scientific community is virtually certain that human activities are influencing the earth's climate system, and in ways unseen in the current geological era. In presenting the science of climate change in chapter 1, we incorporated important elements of the Intergovernmental Panel on Climate Change's Third Assessment Report, as well as more recent observations of climate scientists. We also collaborated with some of the most advanced climate research programs (many of which, coincidentally, happen to be based in Switzerland) to map out scenarios of future global warming.

In chapter 2 we show that global warming and climate change are largely the result of increased consumption of coal, oil, and natural gas, although deforestation and agricultural practices also play a substantial role. Left unchecked and unchallenged, energy use will continue to increase for the foreseeable future, which raises the risk of higher global surface temperatures. An increase in global surface temperatures of more than 3 °C is not out of the question.

Such a scenario is unprecedented in human history and has the potential to be associated with more severe climate change events. Because the situation is unprecedented and depends on complex climate forces, projections of future events are highly uncertain. Nevertheless, climate change will affect us all, some of us more than others. The effects in many areas will be felt primarily through shortages of water and food supplies. Beyond human well-being, climate change will also have an immeasurable impact on non-human ecosystems and biodiversity.

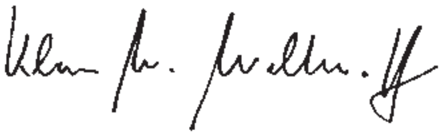
In strictly economic terms, a survey of the literature in chapter 3 shows us that severe climate change events may reduce future economic output by far more than the cost of making adjustments to reduce the risk. However, this observation alone may not justify taking action today to mitigate the effects of climate change. Ultimately, whether to act or not is largely an issue of policy priorities in the face of potentially large and irreversible consequences: much the same way that we purchase insurance to protect against loss, spend resources on a military to counter an attack, and save money in case we become unemployed.

The technical know-how for mitigating the effects of climate change is presently available. From an energy use perspective, the solution rests with either improved energy efficiency or a shift to renewable fuels. A far less complicated way to reverse the effects of climate change is to simply halt deforestation and begin planting trees. Nevertheless, we conclude that energy demand resulting from population and per capita income growth will likely overwhelm energy efficiency gains, and that growth in renewable fuels will likely progress at too slow a pace to bring about a sizable reduction in greenhouse gas emissions.

We develop an investment framework for evaluating the risks and opportunities of climate change in chapter 5. Whether or not you agree with the view that human activity is influencing the climate system is largely irrelevant to the investment thesis. What is important is that numerous policies to combat the threat of global warming are converging to influence people's behavior, alter the risk profile of various businesses, and improve the investment outlook for others. Although such policies may fail to achieve their desired emission reduction goals, they will likely encourage widespread shifts in consumption and industry behavior that will have important investment implications, both in terms of risks and opportunities.

Our intention with this UBS research focus report is to show that climate change is a pivotal force that will shape how we live, work, and interact with each other; that we are a long way from addressing the root underlying causes of climate change; and that the issue of climate change will increasingly manifest itself in financial markets. The impact of climate change will go far beyond simple changes to the weather; and the issue is no longer a question of whether.

On a final note, we would like to thank our colleagues in Global Asset Management's Socially Responsible Investment group for their guidance and thoughtful input in all aspects of this report. This report would not have been possible without their commitment and dedication. We would also like to acknowledge the contributions of leading experts in this field, including Dieter Imboden from the Swiss Federal Institute of Technology, Matthias Kopp from WWF Germany, and Amory Lovins of the Rocky Mountain Institute, each of whom participated in interviews that are featured throughout the report.



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Chapter 1

The science of climate change

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The science of climate change

Higher average surface temperatures are increasingly linked to rising greenhouse gas emissions: as this progresses, the risk of severe climate change events also increases.

Risks from climate change increasing

Rising atmospheric concentrations of greenhouse gases (for example, carbon dioxide, methane, and so on) are the direct result of human activities, such as deforestation, burning of fossil fuels, and agricultural practices. Bear in mind, greenhouse gases are not always bad. Many of the same gases that billow from smokestacks, exhaust pipes, farms, and landfills, occur naturally in the atmosphere. They form a critical part of the intricate natural machinery that regulates the earth's temperature, and in so doing preserve the delicate balance necessary to sustain life.

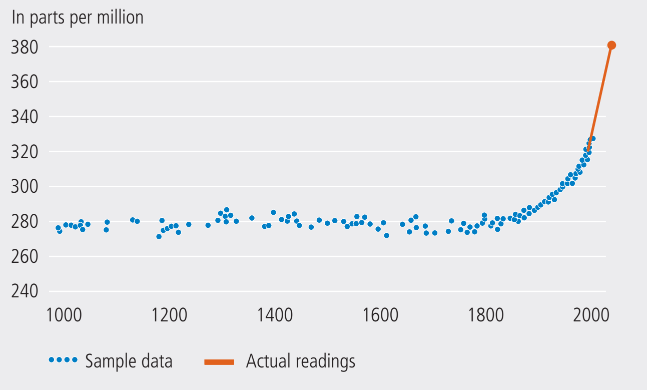
However, human activity has disrupted that balance. An overwhelming amount of scientific evidence has now linked rising greenhouse gas concentrations to an increase in average mean surface temperatures and potentially irreversible changes in the earth's climate system.

Atmospheric concentrations of carbon dioxide have risen roughly 30% since the late 1800s, and concentrations of other known greenhouse gases have increased even more (see Fig. 1.1). Actual atmospheric observations show that concentrations of carbon dioxide have increased to 380 parts per million (ppm) from 280 ppm in the past 200 years. Looking further back, scientists are able to reconstruct prehistoric carbon dioxide concentrations by analyzing air bubbles trapped inside columns of ice collected from the Arctic and Antarctica. This data shows that concentrations are higher now than at any time in the past half million years.

Changes in the earth's climate since the Industrial Revolution are now measurable and quantifiable. Anthropogenic (that is, human-induced) emissions are increasingly linked to evidence of higher average surface temperatures, and, hence, rising sea levels, melting glaciers, and thinning ice and snow cover. According to the Intergovernmental Panel on Climate Change's (IPCC) 2001 Third Assessment Report[1], global mean surface temperatures rose 0.6 °C (accuracy within +/–0.2 °C) during the 20th century (see Fig. 1.2), and

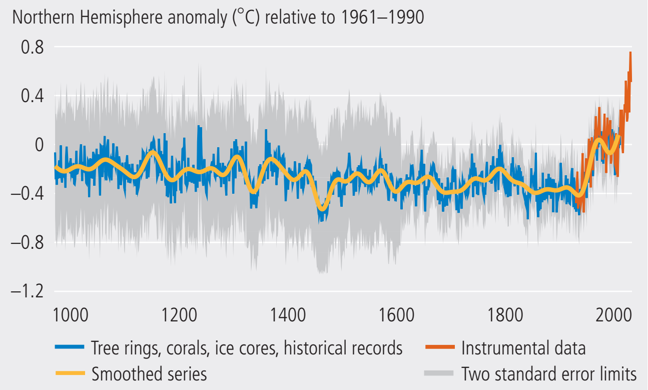
[1] The collective scientific knowledge and observations regarding climate change is presented in the Intergovernmental Panel on Climate Change's (IPCC) Third Assessment Report, completed in 2001. The next report is due for publication in 2007.

Fig. 1.1: Global atmospheric carbon dioxide concentrations



Source: Intergovernmental Panel on Climate Change

Fig. 1.2: Variations in the earth's surface temperature



Source: Intergovernmental Panel on Climate Change

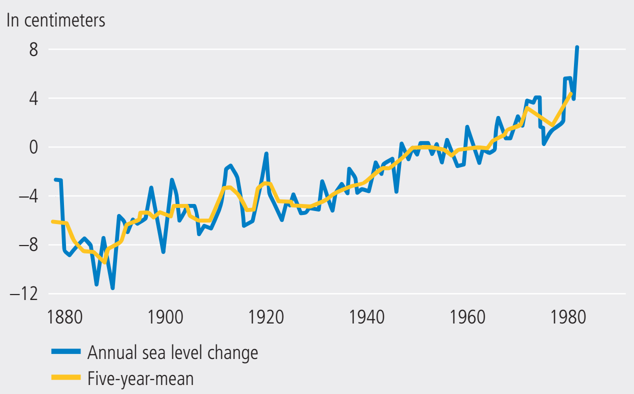
the global mean sea level rose by an annual average of 1–2 mm during the same time period (see Fig. 1.3). Global snow cover decreased by 10% since records were first compiled from satellite observations in the 1960s. Since the 1950s, Arctic sea ice has decreased in extent by 10–15% in the spring and summer months (see Fig. 1.4).

Where do the emissions come from?

The largest greenhouse gas emitters are the US, China, and Europe, in that order. The US is responsible for one-fifth of total global emissions, while China and Europe each hold roughly a 14% share. According to the World Resources Institute, the top 25 greenhouse gas emitters are responsible for 83% of the global total. Economic activity and the population are two of the most important factors that determine greenhouse gas emissions. It is therefore not surprising that the same top 25 emitters are home to 70% of the world's population and 87% of global economic production.

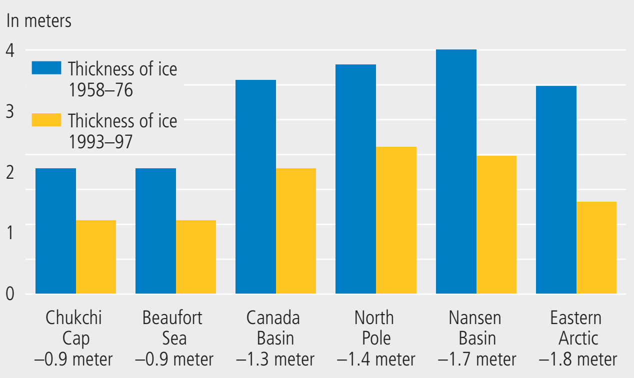
Per capita emissions are highly correlated with per capita incomes, although other factors, such as a country's production of energy products, dependence on international trade, population density, and geography, also matter. As a result, many highly populated developing countries, which produce large amounts of greenhouse gas emissions in absolute terms, contribute far less to global emissions when measured in per capita terms. Although developed and developing countries contribute equally to overall emissions of greenhouse gases, developed countries are far larger emitters when measured on a per capita basis (see Fig 1.5).

Fig. 1.3: Sea level change during the past century



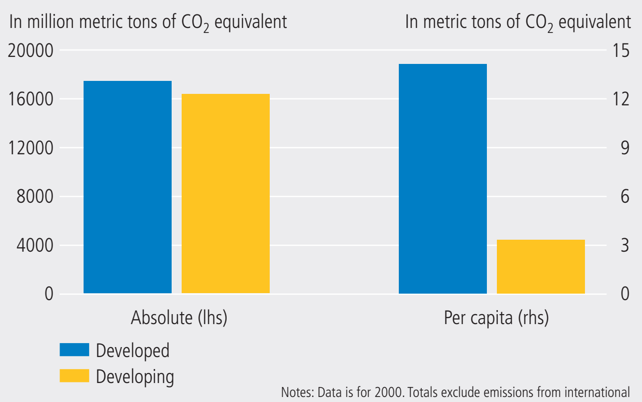
Source: Intergovernmental Panel on Climate Change, adapted from Gormitz and Lededeff (1987)

Fig. 1.4: Thinning of arctic sea ice



Source: Intergovernmental Panel on Climate Change

Fig. 1.5: Absolute versus per capita emissions

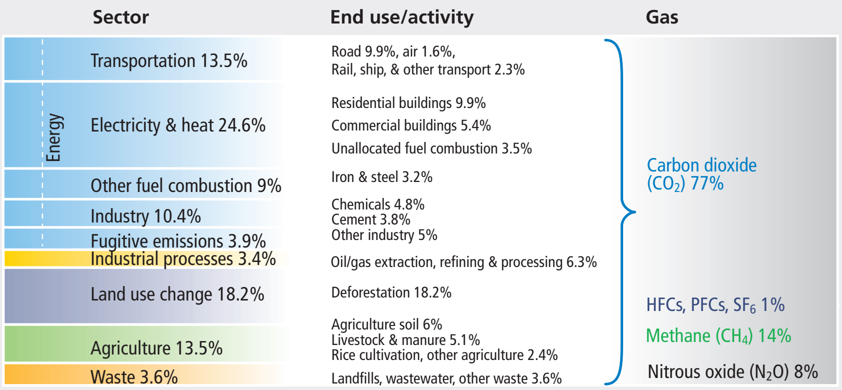


Source: WRI

Notes: Data is for 2000. Totals exclude emissions from international bunker fuels, land use change and forestry.

A geographic distribution of emissions shows only one part of the whole picture. Perhaps even more important is an understanding of the human activities that contribute to greenhouse gas emissions (see Fig. 1.6). The largest single contributor to greenhouse gas emissions is fossil fuel energy use, which is responsible for roughly two-thirds of the world's total, followed by land use management, agriculture, industrial processes, and waste. While burning fossil fuels to obtain energy is the primary agent responsible for greenhouse gas emissions, there is hardly a human activity that does not result in the emission of greenhouse gases in one form or another. The energy consuming activities with the largest impact on greenhouse gas emissions include: road transport; construction, living and working in residential and commercial buildings; chemical production; cement production; steel manufacturing; and the many processes that are involved in bringing energy to consumers.

Fig. 1.6: Greenhouse gas emissions by sector



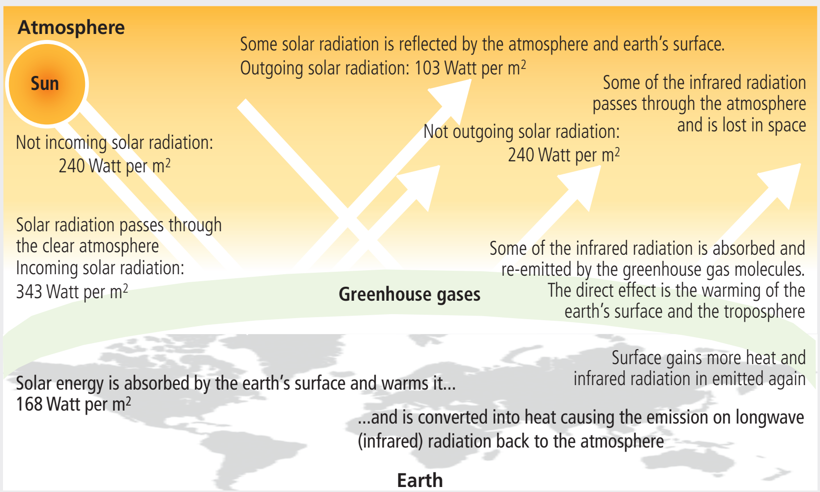
Note: All data is for 2000. All calculations are based on carbon dioxide equivalents, using 100-year global warming potentials from the IPCC (1996), based on a total global estimate of 41,755 million metric tons of carbon dioxide equivalent.
Source: WRI

How the greenhouse effect works

The sun and the earth's atmosphere are the principal components of the greenhouse effect (see Fig. 1.7). Seventy percent of incoming solar radiation penetrates the earth's atmosphere; the other 30% is reflected back into space. The solar energy that is able to permeate the earth's atmosphere is absorbed by the oceans and land masses, and is eventually re-radiated back into the atmosphere in the form of heat (that is, infrared radiation). Some of this heat is again lost to space. However, the heat that remains trapped inside the earth's atmosphere is absorbed and re-radiated by atmospheric gases, such as water vapor and carbon dioxide. This process is known as the greenhouse effect. Without it, the earth's surface temperature would be 33 °C (60 °F) cooler than at present. As concentrations of greenhouse gases increase, the warming effect increases.

All planets with an atmosphere exhibit a greenhouse effect in one form or another. On lifeless planets, such as Venus, for example, a dense concentration of carbon dioxide produces a strong greenhouse effect that raises surface temperatures above 400 °C. On earth, the presence of life enables a constant recycling of greenhouse gases between plants, animals, and complex terrestrial forces, ocean currents, and volcanic activity.

Fig. 1.7 : The greenhouse effect



Source: Intergovernmental Panel on Climate Change

What are the unknowns?

The exact impact of rising greenhouse gas emissions on the climate depends on certain feedback mechanisms, which can either act to accelerate the warming process (positive feedback) or can work in the opposite direction (negative feedback). For example, thinning ice and more limited snow cover might reduce the planet's ability to reflect solar radiation, leading to more energy absorption in the atmosphere. Another positive feedback system involves the mechanism whereby cool ocean waters act as a carbon sink. Rising water temperatures will likely dent the ocean's ability to absorb carbon dioxide (the oceans hold fifty times more carbon dioxide molecules than the atmosphere), leaving more greenhouse gases to float about in the atmosphere. Cloud cover is also at the center of a major debate over positive and negative feedback. One theory suggests that an increase in greenhouse gases will produce more water vapor in the form of clouds. An increase in thicker, dark cloud types would mean that more solar radiation will be reflected back into space. Other thinner cloud types would trap more infrared radiation in the form of heat, and lead to further increases in surface temperatures. The cloud type that will be most relevant in the future is subject to debate.

What is the outlook?

Climate models now predict that rising greenhouse gas concentrations will continue to raise global mean surface temperatures, which in turn, will likely affect other components of the earth's climate system. A range of projections are available in the form of scenarios in the IPCC's Third Assessment Report. These forecasts are now more than five years old, with the next assessment report due out in 2007. The 2001 report projects rising concentrations of carbon dioxide during the 21st century in all forecast scenarios, whereas for the other greenhouse gases the results are more mixed. Despite the projected variability in outcomes for non-CO_2 emissions, the projected increase in carbon dioxide concentrations is sufficient enough to extend currently observed climate change trends.

- **Temperature:** Under a scenario that presumes an aggressive reduction in greenhouse gas emissions, IPCC climate models project an increase in the average surface temperature of the earth by at least 1.4 °C between 1990 and 2100. In the "business as usual" scenario where greenhouse gas emissions are allowed to increase, the models forecast an increase of up to 5.8 °C. Although the potential range of outcomes is quite wide, the projections exceed the observed warming trend during the 20th century. Based on paleoclimate data, there is no known precedent for global warming on this scale in the past 10,000 years.

What are the primary greenhouse gases?

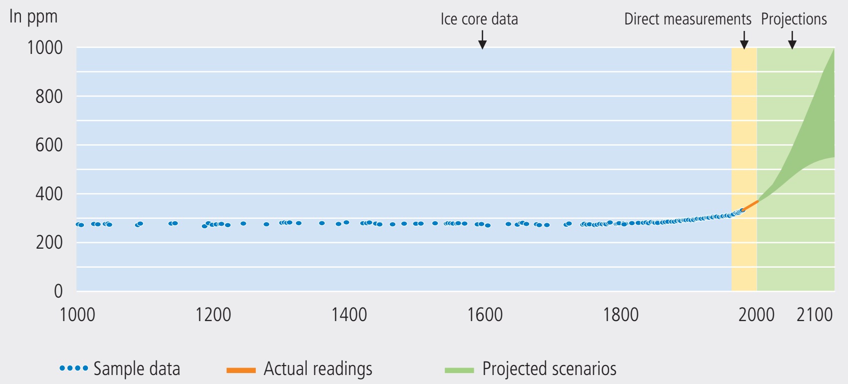
The principal greenhouse gases are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), sulfur hexaflouride (SF_6), tropospheric ozone, chlorofluorocarbons, and water vapor (H_2O). In volume terms, the atmosphere consists largely of nitrogen (78.08%), oxygen (20.95%), argon (0.93%), but in much smaller concentrations are carbon dioxide (.038%), methane (.0001745%), and sulfur hexafluoride (.0000000005%). Clearly, greenhouse gases make up a very small part of the earth's atmosphere. Although rare in atmospheric concentrations (most are measured in parts per million or billion), greenhouse gases are absolutely critical to maintaining the earth's temperature. Small changes in greenhouse gas concentrations can therefore have a large impact on the greenhouse effect.

With such a wide assortment of greenhouse gas emissions, why is the focus so often directed toward carbon dioxide? The answer is related to the concentration of a particular greenhouse gas, its lifespan, and its ability to absorb radiation. Carbon dioxide is not as potent a greenhouse gas in terms of its lifespan and ability to absorb radiation, but exists in far larger quantities. Methane and nitrous oxide exist at far lower concentrations than carbon dioxide, but are far more potent. Scientists devised a concept called "global warming potential" for comparing various greenhouse gases and their potential for influencing the climate. For example, methane is thought to be 23 times more potent than carbon dioxide at influencing the climate over a century-long timeframe. That said, carbon dioxide and its high concentration has the greatest potential to influence the climate, followed by methane and nitrous oxide, which, although more potent, are more scarce.

- **Precipitation:** Average annual precipitation is projected to increase during the 21st century, although regional precipitation could begin to vary quite substantially from current patterns. Areas where precipitation is projected to increase will likely also experience greater year-to-year variability in the amount of precipitation. According to the IPCC, "precipitation will likely increase in high-latitude regions during the summer and winter months. Increases are also projected over northern mid-latitudes, tropical Africa, and Antarctica in winter, and in southern and eastern Asia in summer. Australia, Central America, and southern Africa show consistent decreases in winter rainfall."
- **Ice/snow cover:** Rising surface temperatures will likely have a widespread impact on surface ice and snowfall. The IPCC projects a continued retreat of glacial cover during the forecast period, as well as a further decrease in Northern Hemispheric snow cover, permafrost, and sea-ice extent.
- **Sea level:** Projections of melting surface ice and thermal expansion of the oceans due to temperature increase naturally give rise to an increase in global mean sea levels in the range of 0.09 to 0.88 meters during the 21st century.

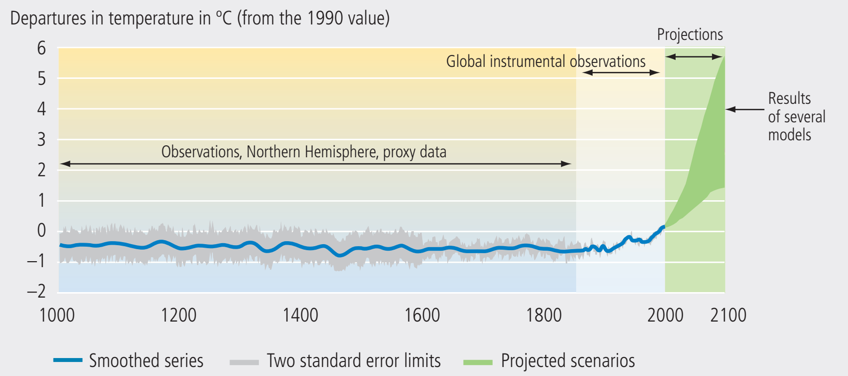
Recent scientific investigation into the subject of climate change has confirmed many of the projections and observations in the Third Assessment Report. In particular, studies have found additional evidence that anthropogenic emissions of greenhouse gases are warming the surface temperature of the earth and its oceans. NASA's Goddard Institute for Space Studies reported that the years 2002–05 represent four of the five hottest years on record since the 1880s, using actual meteorological observations of land

Fig. 1.8: Scenarios of future carbon dioxide concentrations



Source: Intergovernmental Panel on Climate Change

Fig. 1.9: Scenarios of future temperature change



Source: Intergovernmental Panel on Climate Change

and ocean surface temperatures. Research has also confirmed the slow-moving nature of the earth's climate system, which suggests that climate change will continue to gather momentum even if emissions reductions are implemented immediately. Further delays in implementing reduction targets raise the risk that global mean surface temperatures will increase by more than 2°C above pre-industrial levels, a threshold that scientists believe would increase the likelihood of extreme climate change events.

New scientific literature provides evidence that arctic sea ice thinning and glacial retreat is accelerating, largely on account of above-average surface temperatures and changes to precipitation patterns. Moreover, an improved understanding of the relationship between melting ice and sea levels suggests that previous studies may have understated the projected rise in sea levels. Additional research is expanding the knowledge of how changes to precipitation patterns may impact water availability, food supply, and entire ecosystems. For example, persistent high surface temperatures are leading to an increase in beetle populations in Alaska, which are responsible for thinning the region's spruce forests.

Some of these projections and new findings are subject to highly charged scientific and political debate. Science is the province of uncovering answers to the world's unknowns, which inherently involves a complicated and thorough examination of all possible outcomes and even disagreement. Irrespective of the political debate and continued scientific investigation into the secondary effects of climate change, there are two important messages:
- The evidence that human activity is influencing the climate through emissions of greenhouse gases is mounting and is increasingly quantifiable;
- It will be too late to reverse the effects of climate change if we wait to act until science is certain of the outcome.

Chapter 2

Energy use and climate change

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Energy use and climate change

Carbon dioxide emissions from fossil fuel use must be reduced by two-thirds during the second half of this century in order to stabilize atmospheric concentrations and global mean surface temperatures.

Energy use and climate change

The steady increase in fossil-fuel consumption since the Industrial Revolution has had the single-most pronounced effect on changing the greenhouse gas composition of the atmosphere. While land use changes and agricultural activities also account for a large share of greenhouse gas emissions, fossil-fuel combustion generates nearly two-thirds of the world's greenhouse gas emissions (see Fig. 2.1). Therefore, the world's approach to energy consumption will determine whether or not the projected risks associated with global warming and climate change will increase or decrease.

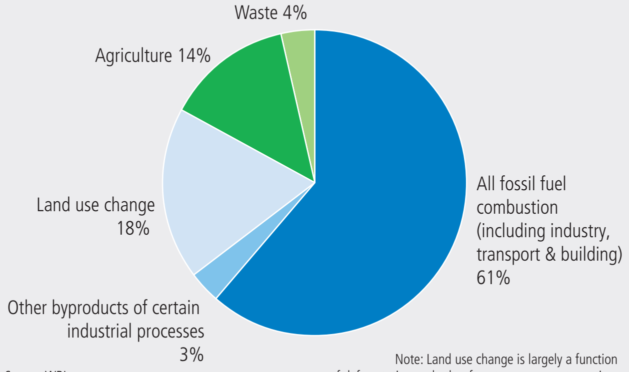
A business-as-usual approach to energy

Overall energy consumption is projected to head higher through the middle of this century, supported by trends in population and economic growth. The UN projects a 35% increase in the world population between now and 2050, primarily in developing countries. In addition, our economic growth projections point to the continued expansion of world economic output, which is driven primarily by rising per capita incomes in highly populated emerging market countries. As per capita incomes rise, energy demand also increases (see Fig. 2.2).

According to our previous UBS research focus report, entitled "Commodities: scarcity of abundance" (dated August 23, 2006), total world energy consumption is projected to increase by nearly 70% during the next twenty years. This increased demand is largely the result of rapid infrastructure development, rising per capita incomes, and continued industrialization in highly populated emerging market countries. Although oil's share of primary energy consumption will likely decline because of strong substitution effects, the relative importance of other fossil fuels, such as natural gas, will likely increase. Despite this substitution effect, greenhouse gas emissions from energy use are poised to rise for the foreseeable future.

Fig. 2.1: Major sources of greenhouse gas emissions

In %

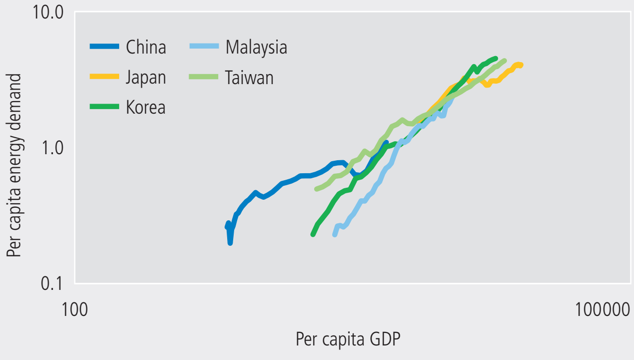


Note: Land use change is largely a function of deforestation and other forest management practices.

Source: WRI

Fig. 2.2: Energy consumption versus per capita income

Per capita energy demand versus per capita income (in log, normalized units)



Source: BP Statistical Review of World Energy (2005), Penn World Table Version 6.1, UBS WMR

The International Energy Agency (IEA) also projects a steady increase in energy consumption during the next quarter century, once again largely driven by rising incomes in developing countries (see Fig. 2.3). Correspondingly, the IEA projects an increase in carbon dioxide emissions during the next 25 years (see Fig. 2.4). Assuming climate change policies remain as they are, worldwide carbon dioxide emissions will grow by 55% between 2004 and 2030, and will more than double in developing countries. Even in the IEA's alternative scenario, which assumes some progress in slowing the rise in greenhouse gases, carbon dioxide emissions still increase by more than 30% through 2030.

The 2,000 Watt scenario

Given that the business-as-usual scenario results in higher energy consumption and greenhouse gas emissions, we present an opposite scenario for reducing greenhouse gas emissions to show what is likely needed to mitigate the effects of climate change. To achieve a lower greenhouse gas emissions trajectory requires improved energy efficiency and increased use of renewable energy sources. Such measures are encapsulated in the views of the "2000 Watt Society," which was developed at the Swiss Federal Institute of Technology in Zürich. The institute maintains that energy use of 2,000 Watt per capita is sufficient for a country like Switzerland to allow for uninterrupted economic growth and an equivalent quality of life (relative to less efficient and higher rates of energy consumption).

By way of example, 2,000 Watt of power is roughly equivalent to uninterrupted use of twenty 100 Watt incandescent light bulbs. To put this in context, per capita energy consumption in Africa is 500 Watt, in Western

Fig. 2.3: Higher energy demand in developing countries…

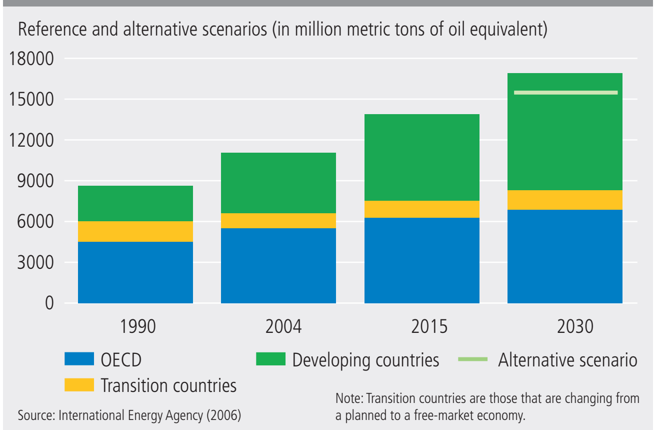


Fig. 2.4: …leads to higher carbon dioxide emissions

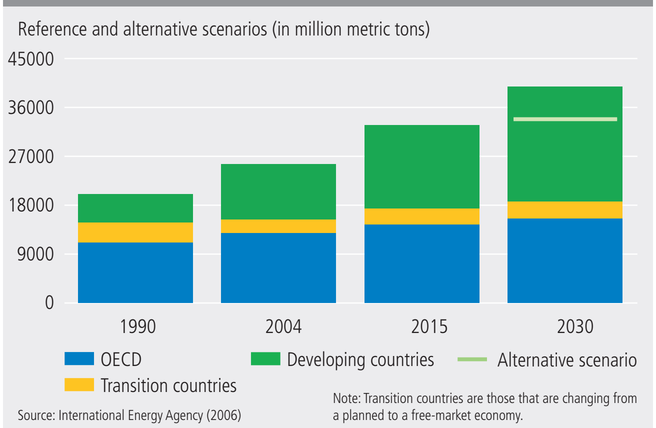
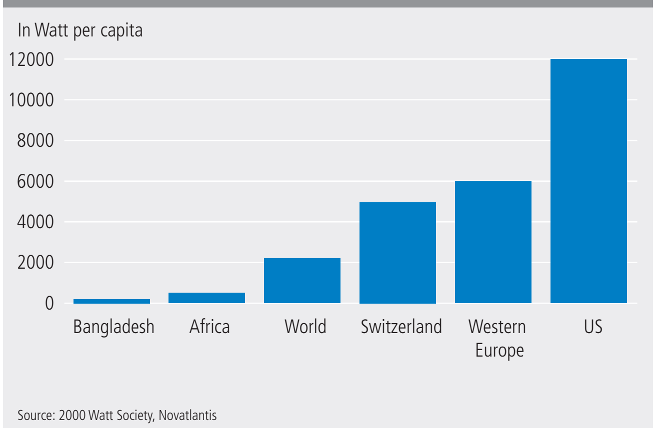


Fig. 2.5: Energy consumption per capita

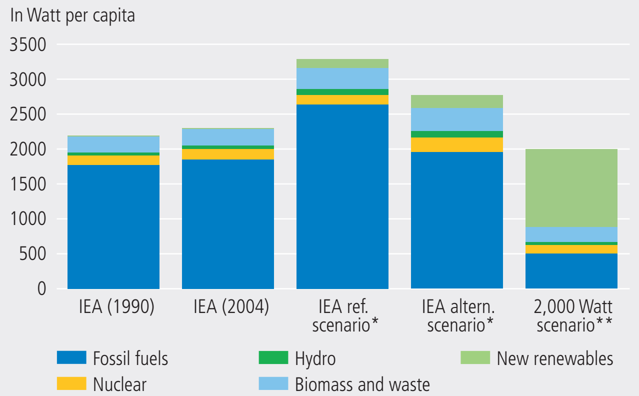


Europe it is 6,000 Watt, and in the US it stands at 12,000 Watt (see Fig. 2.5). Although elements of the scenario are perhaps utopian and would require drastic changes in all parts of society, it gives us a framework for thinking about an alternative energy and emissions path and the projected climate change impact.

As of 2004, global average per capita energy consumption stood at 2,300 Watt. Extending the IEA's reference scenario to 2050 (using 2015–30 growth rates) results in nearly 3,300 Watt of per capita energy consumption (see Fig. 2.6). Even the IEA's alternative scenario extended to 2050 results in per capita energy consumption that is well above 2004 levels. To achieve global per capita energy consumption of 2,000 Watt would involve not only a reduction in per capita energy demand from 2004 levels, but also a sharp change in course away from future demand projections. Most of the shift would have to take place in developed countries to allow for continued growth of energy demand in developing countries.

In addition to per capita energy use, the composition of energy use will have to change substantially to bring about emissions reductions. Consumption of fossil fuels accounts for 80% of total energy consumption, or roughly 1,750 Watt. According to our 2,000 Watt scenario, reducing fossil fuel consumption to 500 Watt per capita would cut fossil-fuel-specific greenhouse gas emissions by roughly two-thirds (see Fig. 2.7). To achieve such an energy mix by the year 2050, new renewables would need to grow at a sustained rate of over 11% per year during the next 45 years, while fossil fuel consumption would need to decrease by more than 2% per year. Meanwhile, the IEA's most environmentally friendly "alternative scenario"

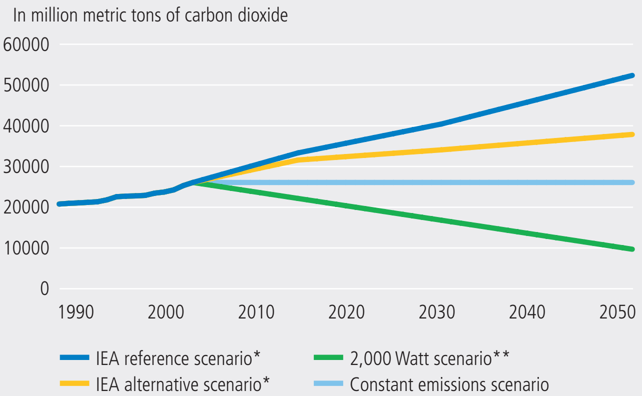
Fig. 2.6: Scenarios of per capita energy use in 2050



Note: * Based on UBS calculations to extend IEA energy demand growth to 2050, using 2015–30 growth rates, and converted into Watt per capita.
** Based on UBS calculations that assume 500 Watt of per capita fossil fuel use and 2,000 Watt of total energy use; nuclear, hydro, biomass and waste retain the same shares as in 2004; new renewables account for the remainder of the 2,000 Watt. New renewables include: solar, wind, small hydro, biofuel, wave, and geothermal power.

Source: International Energy Agency (2006), UN Population Division, UBS

Fig. 2.7: Scenarios of future emissions paths



Note: * Based on UBS calculations to extend IEA emissions growth to 2050, using 2015–30 growth rates.
** Assumes the same emissions factor as the IEA alternative scenario, or roughly 2.83 metric tons of carbon dioxide for each metric ton of oil equivalent fossil fuel consumption.

Source: International Energy Agency (2006), UBS

Fossil fuel consumption and emissions reduction

To reduce the proportion of energy-related greenhouse gas emissions, fossil fuel use would need to decline sharply. To be sure, there are other methods that can partially offset or negate the carbon dioxide emissions from fossil fuel use, such as carbon sequestration and land use changes. Exactly how much to reduce consumption of fossil fuels depends on numerous factors, such as emerging carbon sequestration technology, population growth, economic growth of developing countries, energy efficiency measures, and the future fuel mix (to name a few). Any estimate is only a close approximation to provide an illustration of the trend. For example, slower economic growth rates, different assumptions about how greenhouse gas emissions translate into atmospheric concentrations, and faster development of carbon sequestration technology could all allow for greater use of fossil fuels than 500 Watt per capita. However, even if one accounts for all of these factors, developed country consumption of fossil fuels needs to decline considerably in order to stabilize greenhouse gas concentrations. The crucial point is not the exact level of fossil fuel use, it is the trend.

continues to project both rising demand for fossil fuels, only half as much growth in renewable energies as the 2,000 Watt scenario, and a continued upward sloping emissions path through at least the next quarter century.

Using the fossil fuel carbon dioxide emissions scenarios presented in Fig. 2.7 as a basis, the Department for Climate and Environmental Physics at the University of Bern calculated for us the resulting atmospheric carbon dioxide concentrations and corresponding temperature change by 2200. In order to focus solely on the consequences of burning fossil fuels, we assume that carbon dioxide emissions from land-use changes and agriculture are reduced to zero by 2050 (and by 2200 in the case of the constant emissions scenario). We cap emissions in the IEA's reference case at the level experienced in 2050, but allow carbon dioxide emissions to decrease linearly in the other three scenarios between 2100 and 2200. Emissions in the 2,000 Watt scenario fall to zero in 2200. The results of these carbon dioxide emissions paths are presented in Fig. 2.8 and Fig. 2.9.

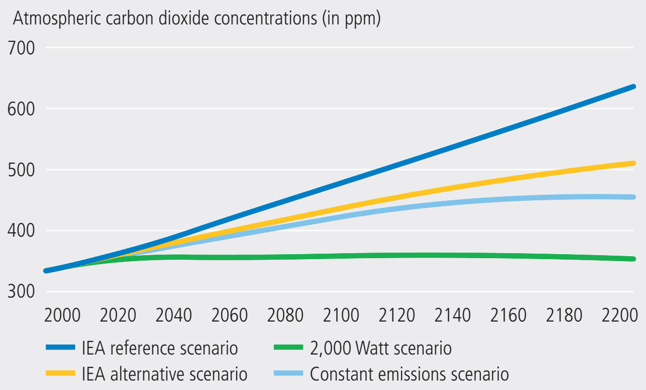
Using assumptions about carbon dioxide emissions in the IEA's reference and alternative energy demand scenarios, the study yields projected temperature change by 2200 of more than 3 °C (relative to pre-industrial levels). Even the constant emissions scenario leads to a temperature increase of more than 2 °C. Only in the 2,000 Watt scenario is global warming limited to below 2 °C.

The University of Bern study concludes that carbon dioxide emissions from fossil fuel use must be reduced to about a third of current emissions during the next 50 years if atmospheric carbon dioxide and surface temperatures are to be stabilized. To keep atmospheric concentrations unchanged at current levels by 2100, carbon dioxide emissions would need to fall below 10 billion metric tons during the last quarter of the century (for stabilization pathways where total anthropogenic carbon dioxide emissions peak in the next one to three decades). A delay in emission reductions leads to higher atmospheric carbon dioxide concentrations and larger temperature impacts for comparable emission reductions. Incorporating the effect of greenhouse gases other than carbon dioxide, as well as greenhouse gas emissions from sources other than energy use, would also yield larger temperature impacts.

Avoiding severe climate change events

Climate change experts are converging on a consensus view that temperature change of more than 2–3 °C relative to pre-industrial levels will all but ensure irreversible and severe climate change events, such as rising sea levels and loss of habitat. Scientific reports released in 2006 estimate that the

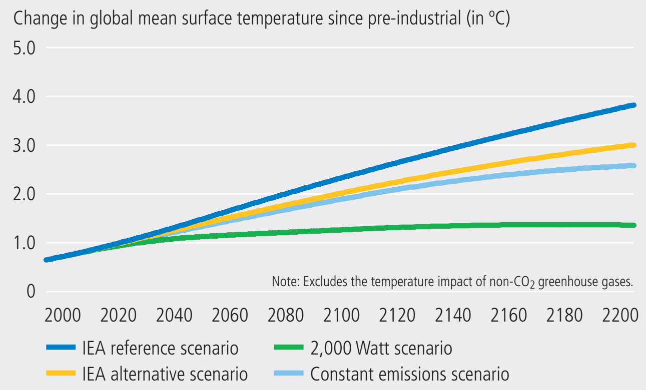
Fig. 2.8: Fossil fuel impact on CO_2 concentrations



Source: University of Bern, Carbon Cycle Climate Model

Note: Excludes non-CO_2 greenhouse gases.

Fig. 2.9: Fossil fuel impact on surface temperatures



Source: University of Bern, Carbon Cycle Climate Model world has warmed roughly 0.7 °C during the 20th century and is now warming at a rate of roughly 0.2 °C per decade. If this rate of warming continues, it would mean that the 2 °C threshold would arrive before the end of the century.

Reducing emissions and stabilizing atmospheric greenhouse gas concentrations are necessary to avoid severe climate change events, although even if emissions were reduced such an outcome is not guaranteed. The business-as-usual energy demand scenario diverges sharply from what is likely necessary to bring about a stabilization in greenhouse gas concentrations. Although global average per capita fossil fuel consumption would need to be reduced by roughly two-thirds in order to stabilize atmospheric greenhouse gas concentrations, developed countries would need to reduce per capita fossil fuel consumption by an average factor of ten to also allow for consumption growth in developing countries. This reduction is based on the simplistic assumption that each person consumes the same amount of fossil fuels.

Ultimately, the risks of climate change are tied to the world's approach to energy use. Renewable energy sources, as well as use of nuclear power, can help to slow the growth in greenhouse gas emissions. However, emissions will continue to move higher without simultaneous gains in energy efficiency and reduced consumption of fossil fuels.

Important developments in climate change research and some of the potential solutions

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What are the most important developments in climate change research?

One debate that got its start in the US concerns a figure showing how the average long-term global temperature may be beginning to resemble a "hockey stick": flat for much of the past two millennia and then turning sharply higher in the 1900s. Despite wide variations in temperature over the past two millennia, climate researchers show that temperatures are reaching higher highs and higher lows. Others who doubt the accuracy of these past data points cite methodological differences over error estimation and measurement techniques. That said, I think there is a majority of scientists nowadays who fully agree that there is climate change and that humanity plays a role. But scientists like to concentrate on the unknown problems, rather than the things that are already known.

For example, trying to figure out the role of the oceans in climate change is rather difficult. Oceans are a huge reservoir of heat; much larger than the atmosphere. It is a turnover system that takes on the order of 1,000 years to complete a cycle. Therefore, if the climate becomes warmer, it would take a long time for the ocean to increase its temperature by a fraction of a degree because it is a tremendously inert system. The oceans continuously transfer heat from lower to higher latitudes, and certain climates depend heavily on this oceanic heat exchange mechanism. Given the role that the Atlantic Ocean plays in regulating the earth's temperature, there are theories about how this conveyor belt may have contributed to ice ages. For example, some theories speculate that this conveyor belt might have been turned off at one point. If it is turned off, heat would no longer flow from the equator to the poles and temperatures at higher latitudes would decline. However, if the speed of the conveyor belt is increased, the temperature at the poles would increase, the ice caps would melt, and sea levels would rise.

Another debate concerns atmospheric chemistry and physics, and how they influence the planet's radiation budget. It is here that things become rather complex, since secondary effects could partially offset primary ones. For example, it is widely accepted that an increase in atmospheric carbon dioxide concentrations causes mean surface temperatures to rise, since less of the earth's heat radiation is lost to space. In turn, higher temperatures cause more evaporation, higher atmospheric moisture content, and, thus, more clouds. Clouds reflect the incoming solar radiation, which could then cool the earth's temperature. In addition, the presence of small particles in the atmosphere, partially caused by human activities, also influences the radiation budget. Therefore, both modelers and experimentalists are steadily refining their concepts by moving from the "easy" processes to the more subtle ones.

So these are the debates. At the moment, for instance, it looks as though the ice is melting faster than we thought. It does not look like the conveyor belt is somehow changing in one direction. But at the moment, we do not know. These are the big unknowns. And you can see the time perspective. Once it becomes absolutely clear that climate change is here, then it means already that we have a long, long breaking distance and limited capacity to change direction.

We see changes. We don't know how they are going to continue, and we do not know all the causes. Of course there have been natural climate fluctuations. But based on the models we have, there is an increasing certainty that something is happening with the climate system and part of this is influenced by humanity. There is no doubt that CO_2 and other greenhouse gases are increasing. It's undebatable. That's clear. The "hockey stick" of temperature change is debated, the one of atmospheric CO_2 increase is not.

What can be done to reduce greenhouse gas emissions?

To reduce greenhouse gas emissions, we must reduce energy consumption. At early stages of development, energy supply is a controlling factor because economic growth is not possible without computers, electric lights, and so on. At later stages, energy consumption is a consequence of increased development, rather than being a prerequisite. In some countries like India, where per capita energy consumption is only 400 Watt, limited energy availability restrains growth and development. In other countries, energy consumption is no longer directly related to growth. In countries like Switzerland, Japan, and the US (5,000 to 12,000 Watt consumption per person), additional spending on energy is no longer necessary to produce higher growth rates. With such wide extremes in energy consumption, scientists wanted to know where the transition from limitation to luxury is located.

Although energy consumption depends somewhat on the climate of a particular area, it is possible to calculate the average amount of energy required for different activities. Scientists arrived at an answer of 1,000 Watt per person. But since this was likely too Spartan relative to current consumption needs in developed countries, the scientists thought that perhaps 2,000 Watt would be an achievable target that would still allow for comfort and uninterrupted economic growth. This is how the 2000 Watt Society was formed.

What role does renewable energy play in the 2000 Watt Society?

New renewables cannot compete in the current energy wasting system we have now. Renewables can only have a chance if overall energy is used more intelligently and efficiently. Of course, it is ridiculous to produce 10,000 Watt of energy per person with solar panels, wind and biomass. But if energy consumption is cut to 2,000 Watt per person, then small contributions from wind power easily become significant.

Considering that this concept was developed in Switzerland, what would a transformation to the 2000 Watt Society imply for a country like Switzerland?

Interestingly enough in Switzerland we have two main activities that are responsible for the vast majority of energy consumption, and, hence, greenhouse gas emissions. It is not industry in Switzerland that is the main contributor, although industry does certainly play a role.

One area is something I call, "Constructed Switzerland." This includes all the buildings, homes, roads, power lines, pipes and overall infrastructure. Constructed Switzerland makes up a tremendous amount of capital. To put it in perspective, each year we invest about CHF 50 to 60 billion, that is 1.4% of the cost needed to rebuild all of Constructed Switzerland. We cannot rebuild Switzerland in five years and have a more sustainable country. But Constructed Switzerland uses up more than 50% of our energy consumption: the way our houses are built (good or bad, well insulated or poorly insulated); where they are located, how much transportation and communication is needed to connect people from the suburbs to work and to the cities. All of this is more or less fixed in Constructed Switzerland and requires a lot of energy. Another third of energy consumption in Switzerland is used for the mobility of people and goods. Some mobility is linked to industrial activity but other mobility is linked to leisure.

The energy consumption of Constructed Switzerland is stabilizing because, although there are more and more buildings, construction is becoming more energy efficient. By contrast, there is an increase in energy consumption in the mobility arena: we have bigger cars, more private transportation, and longer distances to travel. Keep in mind, nobody wants to spend money on energy, per se. What people want are energy services: they want warm houses or to go comfortably from "point a" to "point b". How much energy this energy service needs depends on technical boundary conditions and on consumer tastes and preferences.

One could impose stricter regulations with respect to Constructed Switzerland to achieve lower energy consumption. We know how to reduce energy consumption in Constructed Switzerland without sacrificing comfort. Comfort has nothing to do with the power of my heating system. I just want to have a comfortable temperature. If I build a building in a more intelligent way, I need less energy and still have the same living space and comfortable temperature. And it is easy to build houses that use one quarter or even one tenth of the energy of an average house per square meter, and with only modest increases in cost.

Although there is a big potential to reduce energy demand within Constructed Switzerland, it is more difficult with mobility. In the case of mobility, the energy required to meet consumer tastes and preferences overwhelms the energy required to meet the technical requirements of transportation. Car engines have become more and more energy efficient, but cars have become heavier and larger. The problem is that we will not be able to change people's behavior just by talking to them. However, if they are forced to do it through government intervention, it will be more easily accepted. People generally don't mind adapting as long as everybody has to stick to the same rules – just think of speed limits. Car companies are basically helpless without the support of the regulators.

Provided the regulations are in place, it would take two to three generations to considerably improve the technical energy demands of Constructed Switzerland. With the mobility sector, improving the technical energy demands would take something on the order of a decade. These are the two poles in the 2000 Watt Society.

Is this 2,000 Watt Society achievable given current technology?

Yes, it can already be achieved without new technology. As I said, every new house can be built so that it consumes roughly one-third less energy than the average house, but it takes time. And the technologies to make cars far more efficient are known.

Is it possible for energy providers to still have a viable business alongside sharp reductions in energy consumption, as put forward in the 2000 Watt Society's vision?

Energy providers can differentiate their business model and begin to think in terms of energy services, rather than simply energy. People do not buy energy; they buy energy services. Utilities could pursue a business strategy of consulting with households to first reduce energy consumption, through more efficient light bulbs, for example, and then to shift to renewable energy, by installing photovoltaic cells.

How does one bring the externality of climate change and greenhouse gas emissions into the market price?

Sooner or later the price of energy needs to go up. Currently, the price of energy, especially oil, is highly volatile. The time needed to adjust to higher energy prices is on the order of a few years to several decades. I own my house and there is little I can do to adjust. I can sell my car if gasoline prices rise too much, but the immediate reaction is limited. Moreover, the market price does not always take into account future scarcity. If supply falls short of demand for any period of time, the market price will go up very quickly and the consumer cannot react adequately. This is not very good for the economy in general.

What the industry and what consumers need is predictability. One of the big obstacles from an economic point of view is the unknown development of energy prices. For most infrastructure development projects, such as building houses, the future price of energy is the most important factor for determining whether the cost of energy efficiency improvements is justifiable or not. Because energy prices are volatile, projects are often completed at the lowest possible cost, irrespective of efficiency decisions.

So what I think is that governments, in their position of gauging the collective awareness, should correct for this difference in time scales between the price of oil and a person's ability to adapt. By reducing the volatility of oil prices and providing a clear path for energy price developments (e.g. energy price will increase by 1% per annum), governments can help to improve decision making, while at the same time limit greenhouse gas emissions. Once you have predictability, industry and consumers can adapt. The governments need to set the appropriate boundaries to make the "free market" work.

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Chapter 3

The economics of climate change

Main authors:
Kurt E. Reiman, Wealth Management Research
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The economics of climate change

Reducing greenhouse gas emissions and mitigating the effects of climate change comes at a cost. However, doing nothing may come at a greater cost.

There is no such thing as a free climate

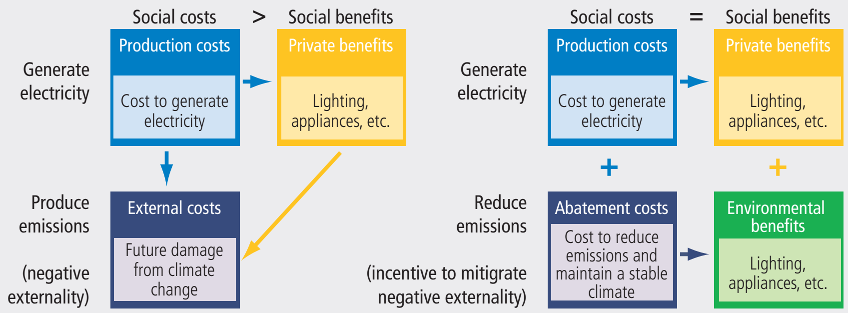
Economic forces are largely responsible for the sharp divergence between the business-as-usual scenario for greenhouse gas emissions and the scenario that would stabilize greenhouse gas concentrations. Today's modern market economy has the capacity to do many things: encourage labor specialization, assign costs and prices, foster entrepreneurship, and allocate the use of natural resources. However, free market forces are unable to control the rise in greenhouse gas emissions: free market transactions do not incorporate the costs to society that would emerge if severe climate change events were to unfold, or the costs that are involved with reducing greenhouse gas emissions to mitigate the risk of climate change. Moreover, many policies, infrastructure, and institutions presently distort market outcomes to favor fossil fuel use, inefficient energy practices, and rising greenhouse gas emissions.

Without the cost of climate change embedded in market prices, there is less of an incentive for the private sector to reduce greenhouse gas emissions and provide the conditions necessary to maintain a stable climate. Therefore, free markets underestimate the future costs to society that would arise if the climate experienced a drastic transformation: a result which many scientists now predict will happen if there is no change to influence free market outcomes.

In the context of economics, the future cost of climate change that results from high concentrations of greenhouse gases is considered an externality: specifically, a "negative externality." An externality results whenever someone's actions generate a cost or a benefit for someone else, the value of which is not reflected in the market price. Since people do not have to pay to maintain a stable climate, they produce emissions without regard to the consequences. This behavior creates additional costs to society in the form of property damage from severe weather and natural disasters, loss of harvest due to drought, the need for infrastructure enhancements, and relocation expenses to avoid high-risk geographic regions (see Fig. 3.1). These costs can also manifest themselves in terms of foregone global economic output.

Fig. 3.1: Different market outcomes

Social costs and benefits flow diagram for electricity generation



Source: UBS WMR

Expanding on the example shown in Fig. 3.1, free markets will produce a higher level of consumption and production of electricity, a higher overall level of greenhouse gas emissions, and lower unit prices for electricity than would otherwise be the case with a "socially optimal" outcome. Free markets provide few incentives to reduce production and consumption of electricity, and to develop and adopt new energy efficiency technologies. This is a consequence of the so-called "tragedy of the commons" (see box on page 29).

Efforts to curb greenhouse gas emissions (either through conservation or technological innovation) will have limited effect in the absence of policies to reduce this negative externality and create mechanisms to internalize the cost of greenhouse gas emissions. Free-riding consumers and producers will leave the problem of reducing greenhouse gas emissions to others and avoid doing anything themselves. If enough people behave in this way, individual efforts to reduce greenhouse gas emissions will likely prove insufficient.

Regulated markets can produce a socially optimal outcome because the presence of abatement costs increases incentives for consumers and producers of electricity to reduce emissions (see Fig. 3.1). Compared to the free market case, internalizing abatement costs leads to higher unit electricity costs, lower electricity output & consumption, and greater incentives to raise energy efficiency.

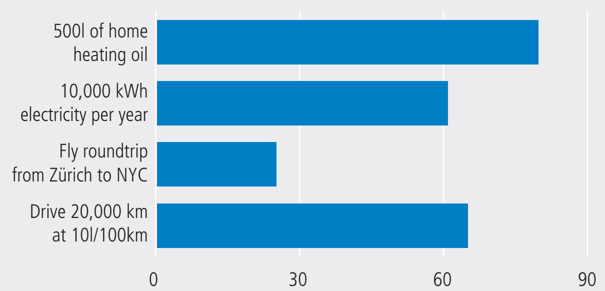
Fig. 3.2 shows estimated costs to offset carbon emissions for selected activities, based on the current exchange-traded price of carbon emissions. These offset costs can be loosely interpreted as the cost of carbon dioxide abatement. For example, the estimated cost to offset carbon dioxide emissions from the fuel consumed in a transatlantic flight is roughly USD 25. This fee could then be used to plant trees, subsidize renewable energy production, and invest in energy efficiency technologies. The issue facing policy makers is not only how, but also whether or not it makes economic sense to incorporate such a carbon price into the market price, and create incentives for firms and individuals to reduce greenhouse gas emissions (see appendix for an overview of the available policy options).

Reconciling the two scenarios

Without policies and incentives to change how people and industries behave, greenhouse gas concentrations will continue to increase. Sure enough, there is an uncoordinated industry effort to reduce greenhouse gas emissions by improving building efficiency and lowering energy intensity. Yet energy-efficiency measures are primarily aimed at reducing operational costs

Fig. 3.2: Estimated cost of carbon dioxide emissions

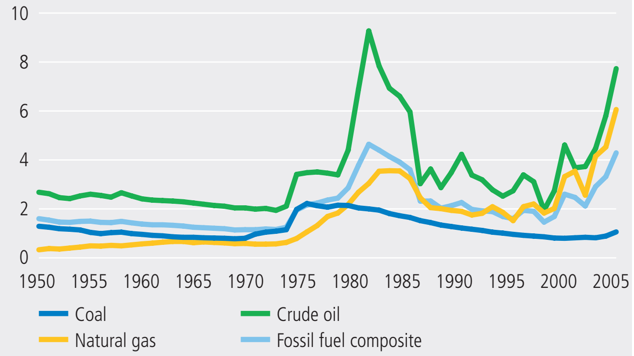
For selected activities (in USD)



Source: Climate Care, UBS

Fig. 3.3: Fossil fuel prices are highly volatile

Real price (in chained 2000 USD per million British thermal units)



Source: Energy Information Agency (2006) and living expenses, not at incorporating external costs. Moreover, energy efficiency is highly sensitive to fossil fuel prices, which are highly volatile and depend mostly on expected future scarcity and supply & demand relationships, rather than the expected future costs of climate change (see Fig. 3.3). There are also plenty of other factors influencing energy demand that can overwhelm the gains from energy efficiency measures, as we will demonstrate in chapter 4.

Most objections to greenhouse gas reduction policies are based on the view that such actions involve an economic cost and may reduce competitiveness. This is only natural since, as we have already established, resolving the divergence between the business-as-usual emissions scenario with the one that would stabilize atmospheric greenhouse gas concentrations essentially boils down to a matter of assigning costs. However, the cost of mitigation is not the only relevant cost. One can also assign a cost to future climate change events that might occur if we chose not to address greenhouse gas emissions. The decision to reduce greenhouse gas emissions today, to mitigate the future effects of climate change, depends on whether the cost of acting now is less than or greater than the cost of future climate change events. If it is less expensive to act now, then we would be well-pressed to take immediate action.

Assigning a cost to future climate change events

Forecasting the impact of greenhouse gas emissions on global temperatures is far more precise than estimating the local impact on climate variables. Likewise, estimating the impact of climate change on the economy is difficult and complicated because this particular avenue of academic exploration is still relatively new, and also because economic models often depend on a long series of climate change scenarios that are themselves uncertain at a regional level (see Fig. 3.4).

Economic literature has generally ignored the role of the climate as a determinant of income and wealth, opting instead to focus on capital, labor, technology, and natural resource endowment. Given the enormous shift out of agriculture into manufacturing and services that has taken place in developed and developing countries alike, some would argue that economic growth is no longer sensitive to changes in the physical geography of the planet.

Perhaps in reaction to the increasing attention that climate change is receiving in public policy circles, economists are working to estimate the impact of geographic and climate variables on productivity, economic growth, and wealth. Using geographic mapping (by latitude and longitude

Tragedy of the commons

Overgrazing of an open pasture is the classic example of the "tragedy of the commons." Herders always have an incentive to increase their flock because each animal yields additional income. Yet, the pasture will degrade if too many animals are allowed to graze on the land. Since there is open access to the pasture, an individual herder cannot capture any benefit from conservation. Therefore, no one will conserve the land, which then results in overgrazing. This phenomenon is known as the "tragedy of the commons," a situation that typically develops in the exploitation of shared resources. Similar to public goods, no one can be excluded from using a shared resource. However, unlike public goods, shared resources are divisible in that consumption by one takes away from the amount available to others.

We can also view the atmosphere as a "commons." Much like uncontrolled use and overgrazing, unrestrained greenhouse gas emissions produce an altered climate. Energy producers have little incentive to cut output to lower greenhouse gas emissions. If one company were to reduce its supply of energy in an effort to conserve the climate, another company would come along and fill the demand gap. This behavior encourages all producers to raise output to meet demand, and the resulting greenhouse gas emissions are higher than the socially optimal level. As with overgrazing, this behavior yields climate change. People continue to consume energy: aware of their individual behavior, while mostly unaware of the collective.

cells) of economic output, population, and global environmental data, Nordhaus (2006) projects how climate change will impact economic output, according to two scenarios.

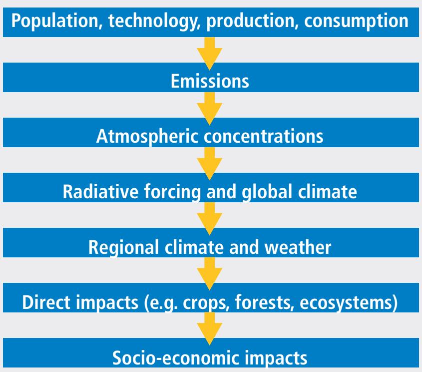
- **Warming with no precipitation change:** assumes a doubling of carbon dioxide concentrations and a latitude-dependent 3 °C rise in global average surface temperatures.
- **Warming with mid-continental drying:** assumes the same initial details as the first scenario but adds a variable that allows for less rainfall on inland areas and greater rainfall on coastal areas.

Both scenarios show that climate change has a negative estimated impact on global output. The second scenario produces a larger negative outcome than the first, which suggests that changes in precipitation patterns amplify the standard temperature effect (see Fig. 3.5). The results of this study demonstrate a larger negative impact than earlier research on the subject. Although Tol (2002) concludes that a smaller 1 °C increase in global mean surface temperatures would yield a net positive impact on global economic output, larger increases in surface temperatures produce results that become progressively more negative. As we outlined in chapter 2, the impact of the business-as-usual scenario for energy use on global mean surface temperatures yielded an increase in excess of 3 °C. According to the UK government study on climate change, warming of 5–6 °C, and the associated risks of severe climate change events point to as much as a 10% erosion in the level of global gross domestic product (GDP), with poor countries experiencing even greater damage costs. (Stern, 2006)

Most models show that the economic effects will vary considerably from place to place. According to Tol et. al., (2004), some regions will experience a boost to economic output, such as Canada and Russia, while other regions will be harmed, such as equatorial Africa, Bangladesh, and India. In general, climate change will likely exact the greatest economic toll on poor countries, nations which have contributed the least to the emerging climate problem. In particular, climate change models project a strong impact on water availability and, by extension, agriculture. Water infrastructure and irrigation are usually inadequate in the least developed countries, while agriculture often contributes a larger share to overall economic output. Therefore, any impairment of these basic necessities, combined with a lower capacity to adapt, will likely lead to more harmful economic and non-economic consequences of climate change in the poorest countries. Adaptability would tend to lessen the impact of climate change, but requires “complex behavioral, technological, and institutional adjustments at all levels of society, and not all population groups will be equally adept at adapting.” (Tol et al., 2001)

Fig. 3.4: Economic impact of greenhouse gas emissions

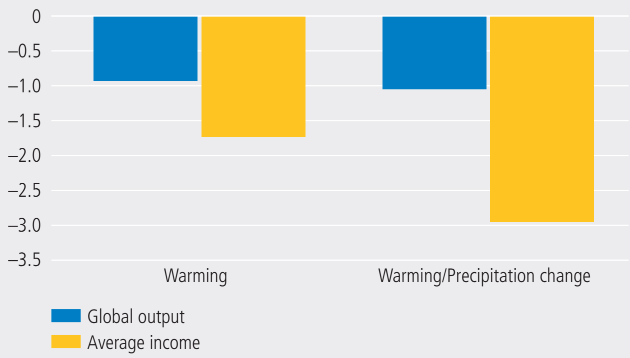
Flow chart



Source: Hope (2005)

Fig. 3.5: Impact of climate change on economic output

Change in the level of GDP according to two scenarios and two weightings (in %)



Source: Nordhaus (2006)

One must be careful to understand the limitations of these studies. Although detailed and statistically rigorous, models that forecast how climate change will affect economic output leave many real-world dynamics unexplained. Furthermore, these models often do not explain how extreme climate change events, as well as the resulting changes in biodiversity, human health, and ecosystems, would impact economic output. Because of the complex dynamics involved, there is considerable room for additional investigation. That said, research into the effect of severe climate change events on global economic output increasingly points to negative consequences for the world economy.

Assigning a cost to emissions reductions
As we outline in the appendix, there are many options for mitigating and adapting to the effects of climate change. Reducing greenhouse gas emissions requires an international consensus, numerous technical applications, and a solution that is cost-effective and does the least harm to economic growth. Whatever the policy, each one places a price on greenhouse gas emissions.

Standards and taxes are aimed directly at the polluting source, but may not achieve the desired effect of lowering overall emissions. Moreover, standards are not the most cost-effective option for pollution control because they require the same changes from everyone without regard for the cost of meeting the standard. Trading emission rights is the most cost-effective policy option and has proven effective at reducing emissions from a manageable number of large point sources. However, trading systems first require policymakers to establish a meaningful emissions cap and then distribute rights: this often involves compromise. They also may be less effective at regulating smaller point sources, such as emissions from vehicles and buildings.

All approaches to reducing greenhouse gas emissions require a strong global regulatory environment to be effective. Without it, meaningful reductions in greenhouse gas emissions are unlikely because the problem

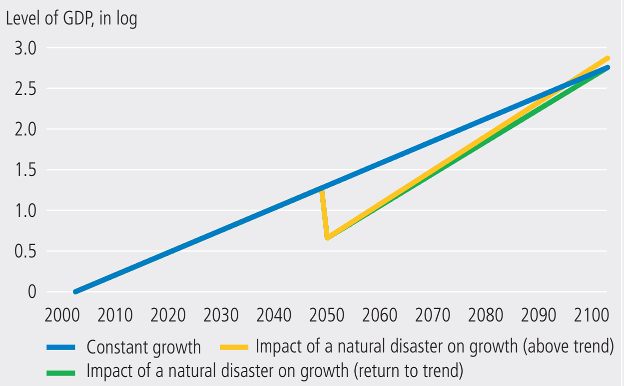
Is climate change potentially good for economic growth?

Some would argue that natural disasters and the widespread adaptation that will likely flow from a world transformed by severe climate change might actually be good for economic growth. If a flood or forest fire were to destroy important infrastructure, the immediate impact might be that growth slows sharply in the region, as people figure out how to respond and businesses are closed. The longer-term result might actually spur economic growth as rebuilding takes place. If the resulting rebuilding improves productivity, the growth path might even lead to an economy reaching a higher growth path than would have been the case in the absence of a natural disaster.

Fig. 3.6 shows the impact on economic growth that occurs when a natural disaster strikes a region. Rebuilding raises the growth rate, which eventually brings the economy back to its initial trajectory. The economy may even continue growing at a faster pace if productivity is enhanced.

Although climate change and natural disasters may raise the growth rate, the discussion conceals an important point. Growth may be higher, but the reason for the additional growth is to restore lost wealth. In a general sense, economic growth adds to wealth. Therefore, restoring wealth following a natural disaster requires a faster growth rate just to bring an economy back to its original state. So although natural disasters may be good for growth, they are bad for wealth and welfare.

Fig. 3.6: Effect of a natural disaster on GDP growth



Source: UBS

of negative externalities will remain unchecked and unchanged. Furthermore, industries would likely find an incentive to relocate to areas that are less regulated, extending the free-rider problem and the tragedy of the commons.

A comprehensive UK government study released in October 2006 estimates a range of climate change mitigation costs for lowering greenhouse gas emissions from fossil fuel consumption. The cost estimates depend on technological development, energy demand growth, carbon capture and storage costs, and fossil fuel prices. The study estimates that reducing greenhouse gas emissions so that concentrations stabilize at 550 ppm would involve an average annual cost ranging from –1.0% (positive net benefit) to nearly 3.5% of GDP (see Fig. 3.7). The central tendency projection shows that average annual costs will rise to roughly USD 1 trillion in 2050, or just under 1.0% of GDP in that year. To put this 1.0% cost in context, if world economic growth were to grow by 2.5% each year through 2100, this cost would shave one hundredth of 1% from growth during the period (i.e., growth would fall from 2.5% to 2.49%). More aggressive and less flexible emission reduction targets would involve potentially higher costs.

Costs of cleanup versus costs of severe climate change

With cost estimates of severe climate change events running in double digits (in percentage terms as a subtraction from the level of global GDP) and estimates of the cost of mitigating climate change in the low single digits, it would seem on the surface that mitigation efforts are less expensive than the cost of waiting for climate change events to unfold. However, the path of future GDP growth can have a material impact on which cost ends up being greater. To determine which cost is greater, one would need to calculate the present value of future scenarios for GDP.

To simplify the analysis, we constructed three hypothetical GDP growth paths, with each one based on a different assumption about the projected cost of climate change.

1. The first scenario assumes that the cost of "cleaning up greenhouse gas emissions" subtracts roughly 1% from the level of GDP by 2100 (compared with a constant annual growth rate during the period of 2.5%). This scenario attempts to account for the costs associated with reducing greenhouse gas emissions to lower the risk of severe climate change events.
2. The "climate change with faster early growth" scenario assumes that severe climate change events subtract 20% from the level of GDP by the end of the century. The negative effect of severe climate change events on GDP occurs late in the century. Prior to this, GDP grows faster than

Fig. 3.7: Global costs of cutting fossil fuel emissions

Positive figures represent costs, negative figures are benefits (as a % of global GDP)

	2015	2025	2050
Central case	0.3	0.7	1.0
Pessimistic technology case	0.4	0.9	3.3
Optimistic technology case	0.2	0.2	–1.0
Low future oil and gas prices	0.4	1.1	2.4
High future oil and gas price	0.2	0.5	0.2
High costs of carbon capture and storage	0.3	0.8	1.9
A lower rate of growth of energy demand	0.3	0.5	0.7
A higher rate of growth of energy demand	0.3	0.6	1.0

Note: Global GDP in 2005 was estimated at $35 trillion. It is assumed to rise to $110 trillion by 2050, a growth rate of 2.5% per year. Stabilize greenhouse gas concentrations at 550 ppm.

Source: Stern (2006)

the scenario for cleaning up greenhouse gas emissions. Because the level of GDP grows linearly in this scenario, growth is higher today and lower in the future.

3. The "climate change with slower growth throughout" scenario also assumes that severe climate change events subtract 20% from the level of GDP by the end of the century. However, GDP grows at a constant rate during the period.

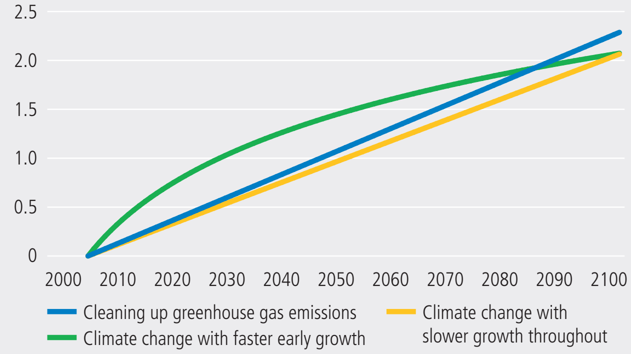
As Fig. 3.8 shows, the absolute level of GDP in 2100 ends up being highest in the "cleanup" scenario and lowest in the two climate change scenarios. However, the important measure for evaluating the cost of climate change is not the absolute level of GDP in 2100, but rather the present value of the future path of GDP. In this regard, the "climate change with faster early growth" scenario has the highest present value because of the higher near-term growth rates. Meanwhile, the "climate change with slower growth throughout" scenario has the lowest present value thanks to the slower rates of growth that persist throughout the entire period. Alternatively, if the same three scenarios are phased in during a much shorter timeframe, for example between now and 2050, the "cleanup" scenario yields the highest future GDP path, and both of the "climate change" cost scenarios prove the least favorable for economic output (see Fig. 3.9).

Summary of the economics of climate change
Because climate change is expected to occur over such a long time period, and because the course of events is highly uncertain, it is difficult to say concretely that cleaning up greenhouse gas emissions will be less costly than climate change events. Although baseline cost estimates of climate change mitigation appear on the surface to be lower than the worst-case cost estimates of future climate change events, the actual outcome depends on a wide number of variables and assumptions.

That said, people frequently purchase life, health, and personal property insurance without complete knowledge of their own future risk of impairment. Countries spend vast sums of money on national defense without fully knowing the specific threat to their strategic interests. Individuals save money for future consumption without knowing how long they will live. Climate change has the potential to sharply lower the level of future economic output, and has the potential to inflict damage on infrastructure, human capital, and physical capital, which, in turn, would lower wealth and welfare. An insurance policy in the form of spending to mitigate the risks of climate change is increasingly justifiable, given the potential cost of doing nothing.

Fig. 3.8: Comparison of different GDP paths to 2100

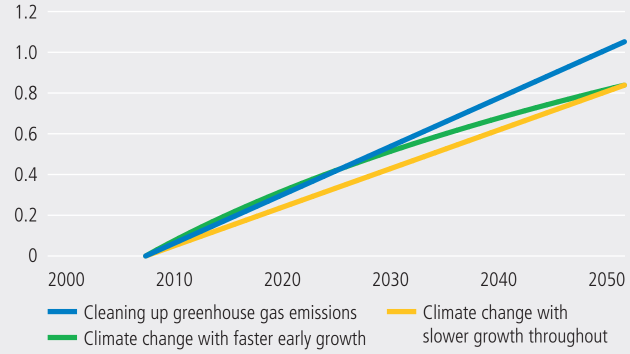
Cleanup costs versus climate change costs (level of GDP, in log)



Source: UBS

Fig. 3.9: Comparison of different GDP paths to 2050

Cleanup costs versus climate change costs (level of GDP, in log)



Source: UBS

How current technology can produce reductions in greenhouse gas emissions

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What are the highest priority areas for technological development to bring about reductions in greenhouse gas emissions? What sort of leading technologies need to come first?
You seem to be very interested in future technologies to solve our climate change problem. However, that is not really my focus. The technologies that are already on the market offer everything we need and more, to reduce greenhouse gas emissions dramatically. Enhancing end-use efficiency is the most vital step towards creating a climate-safe energy system, but switching to fuels that emit less carbon will also play an important role.

Can you elaborate on some key areas of action regarding energy efficiency and fuel switching?
Two main areas for action are in transportation and electricity. Although transportation is widely considered the most intractable part of the climate problem, partly due to large traffic volume growth in emerging economies, transportation offers enormous efficiency opportunities. There is huge potential to improve fuel efficiency by optimizing the physics – reducing drag, and reducing weight with ultra-light and ultra-strong materials, such as carbon fiber composites. Moreover, ultra-light cars could greatly accelerate the transition to hybrid electric and ultimately to hydrogen fuel-cell based cars that use no oil at all. Artfully combining lightweight materials with innovations in propulsion and aerodynamics could cut oil use in cars, trucks, and planes by two-thirds.

Are these efficiency gains possible without negatively affecting driving comfort and cost?
The concepts that we are proposing are based on offering the same attributes, such as comfort, volume, acceleration, acoustics, and styling, with additional safety. Moreover, it is not more expensive. The perception that lightweighting costs more is wrong. Quite the contrary, lightweighting is actually "free" due to the fact that lightweighting based on carbon fiber composites involves much simpler production processes and a two- to threefold smaller propulsion system. This offsets the more expensive materials costs. For example, composite cars do not require body or paint shops. Furthermore, it does not make sense to compare the costs of 1 kg of steel with 1 kg of carbon fiber and conclude that carbon fiber is more expensive. With carbon fiber you need much less material. And although the material still costs more, it is more than paid for by roughly 99% lower tooling cost, and cheaper assembly because there is no body shop, an optional paint shop, and a smaller powertrain.

You mentioned the potential efficiency gains in electricity. What is possible here?
There are two main areas to influence in the electricity area: On the one hand, there is great potential in improving electric end-use efficiency. On the other hand, we need to improve the efficiency and carbon intensity of production.

The potential for end-use efficiency is huge. At least 40–60% of electricity use could be saved through efficiency measures in all areas, including industry, buildings, household appliances, and electronic equipment. The most detailed calculations show larger savings, around 75–80%, at an average cost lower than just the operating cost of existing coal or nuclear power stations.

Regarding the production of electricity, the key strategies are improved generation efficiency and a switch to lower-carbon fuels. Two thirds of the energy input is lost at the power plant, and another 7–9% in transmission and distribution. In this context, decentralized energy supply can play a major role in reducing these inefficiencies. I want to stress that there actually exists an ongoing "micro power revolution." Micro power is the decentralized generation of electricity with renewables, such as wind, geothermal, small hydro, solar photovoltaics, and biofuels, plus fossil-fueled combined heat and power. Not many people realize that these small, and allegedly costly systems, have already surpassed nuclear in output and capacity. Worldwide, micro power produced one-sixth of the world's electricity and one-third of its new electricity in 2005, when it added four times the electricity and eleven times the capacity that nuclear power added. There are reasons for this growth: micro power has much lower financial cost and risk than nuclear power or other central thermal power stations. That helps to explain why micro power is financed very largely by private risk capital, whereas no new nuclear project is so financed: they are bought only by central planners.

Critics say that due to the variability of renewables you wouldn't be able to cover baseload power with renewables, hence you need "reliable" sources such as nuclear.
This is not true. You can cope with variability. Variability of renewables is lower than the demand variability. Also, if one spreads out different renewables across hundreds of kilometers and diversifies the types of technologies used, decent weather forecasts can manage the variability. For example, wind and solar work particularly well together, partly because the conditions that are bad for wind, which are essentially calm and sunny weather, are good for solar, and vice versa. In fact, when properly combined, wind and

solar facilities are more reliable than conventional power stations. Don't forget, at any particular time 5–8% of the nuclear power plants do not work either, and typically they fail unexpectedly, in large decrements, for long periods. Hence, utilities are used to managing this variability and working with a safety margin. Most importantly, most national grids have already bought more backup capacity than they would need, so as to cope with the intermittence of large thermal stations, and so manage the variability of even very large shares of renewables like wind and solar power.

If energy efficiency has so much potential, why isn't everybody pursuing it?
One obstacle is that many people have confused efficiency, which means doing more with less, with curtailment, discomfort or privation, which mean doing less or worse or without. Another obstacle is that energy users do not recognize how much they and their societies can benefit from improving efficiency, because saved energy comes in millions of invisibly small pieces, not in obvious big chunks. There are about 60–80 specific obstacles (that is, market failures) to buying energy efficiency; each can be a show-stopper, but each can also be turned into a business opportunity.

The climate debate has unfortunately been misguided as implying large costs of climate protection. In my view there has been a "sign error" here. In fact, the opposite is true. Climate protection can save money, because energy efficiency costs less than the fuel it saves. Interestingly enough, 100% of the experts involved in energy efficiency measures talk about profits, and 100% of the politicians concentrate on the costs. The fact is that using energy more efficiently offers economic benefits not just in terms of stopping global warming, but because saving fossil fuel is a lot cheaper than buying it. Preventable energy waste costs the global economy more than USD 1 trillion a year. For example, saving each barrel of oil through efficiency improvements costs only USD 12, about one-fifth of what petroleum sells for today. Take another example: delivering a kilowatt-hour from a new nuclear plant costs at least three times, and more typically about ten times, as much as saving one through efficiency techniques. Thus, every dollar spent on efficiency would displace roughly three to ten times as much coal (and therefore carbon emissions) than spending the same dollar on nuclear power. Also the efficiency improvements could go into effect much more quickly because it takes so long to build reactors. Since nuclear power provides far less climate solution per dollar and per year than its competitors, it would make climate change worse.

What is the best political framework to allow for current technology to solve our climate change problem?
The solution is not in more taxes and subsidies. Ideally, the best framework would be the free market framework; a truly free market would automatically lead to an efficient use of resources. However, this would basically mean the opposite of current policy, which tends to favor the costliest options with the most powerful political support.

Any specific proposals for the areas of electricity generation and transportation?
In the case of utilities, for example, one of the main obstacles is that almost everywhere, utilities are actually rewarded for selling more energy and penalized for cutting their customers' bills. Luckily, this problem is easy to fix: state regulators can align incentives by decoupling profits from energy sales, and then allow utilities to keep some of the savings from trimming energy bills.

In the case of cars, I regard so-called "feebates" as the most powerful policy response: much more powerful and more efficient than fuel taxes. This means charging fees on inefficient new cars and returning that revenue as rebates to buyers of efficient models. If done separately for each size class of vehicle, so there is no bias against bigger models, feebates would expand customer choice instead of restrict it. Feebates would also encourage innovations, save customers money, and boost automakers' profits.

Amory Lovins, a MacArthur Fellow and consultant physicist, has advised the energy and other industries for nearly three decades as well as the U.S. Departments of Energy and Defense. Published in 29 books and hundreds of papers, his work in about 50 countries has been recognized by the "Alternative Nobel," Onassis, Nissan, Shingo, and Mitchell Prizes, the Happold Medal, nine honorary doctorates, and the Heinz, Lindbergh, Time Hero for the Planet, and World Technology Awards. He advises industries and governments worldwide, and has briefed 18 heads of state. He co-founded and leads the Rocky Mountain Institute, an independent, market-oriented, nonprofit applied research center.

Chapter 4

Sources of greenhouse gas emissions

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Sources of greenhouse gas emissions

Although options abound for lowering greenhouse gas emissions, outright reductions are unlikely.

A practical approach

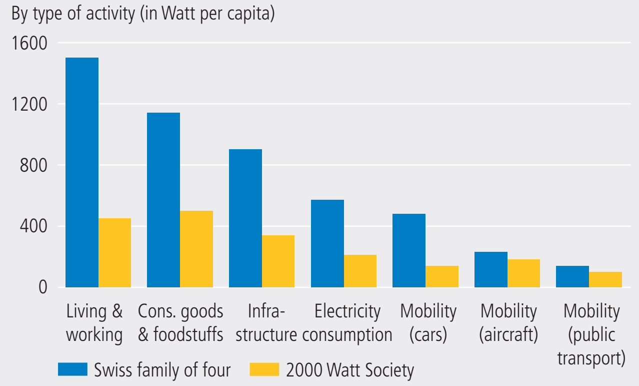
Many solutions to reduce greenhouse gas emissions are available, but they would require widespread behavioral and societal changes to be realized (see Fig. 4.1). Buildings and electricity consumption are two areas with particularly large energy-saving potential (see Fig. 4.2). For example, the highest energy efficiency standard for a Swiss house is 350 Watt to 550 Watt per person, compared with the current national average of 1,400 Watt. Simple energy efficiency gains are also possible in lighting, which consumes roughly 20% of all generated electricity: the latest technology for light emitting diodes (LEDs) can produce far more visible light per Watt of energy than an incandescent light bulb.

In the following four subchapters, we will describe in detail the potential options for reducing greenhouse gas emissions. The analysis is broken down into the areas of energy delivery (the supply side of energy use), buildings, transportation, and industrial processes (the demand side of energy use). The objective of this chapter is fourfold:

1. to illustrate the business as usual outlook for greenhouse gas emissions in these four key activities;
2. to show where the potential exists for mitigating the risks of climate change through reducing greenhouse gas emissions;
3. to evaluate the policy options and regulatory risks; and
4. to arrive at a conclusion about the future path of greenhouse gas emissions by showing where emissions reductions are most likely and where they are unlikely.

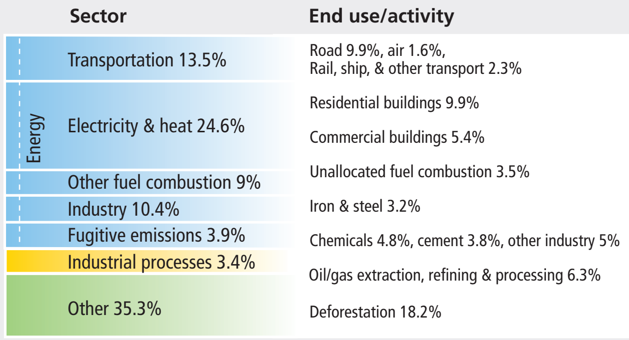
The subcurrent to this discussion is also to show where there is potential for people to make changes on a personal level to reduce their own impact. The investment implications that flow from this discussion are presented in chapter 5.

Fig. 4.1: Energy consumption of the 2000 Watt Society



Source: 2000 Watt Society, Novatlantis

Fig. 4.2: Greenhouse gas emissions by sector



Note: All data is for 2000. All calculations are based on carbon dioxide equivalents, using 100-year global warming potentials from the IPCC (1996), based on a total global estimate of 41,755 million metric tons of carbon dioxide equivalent.
Source: WRI

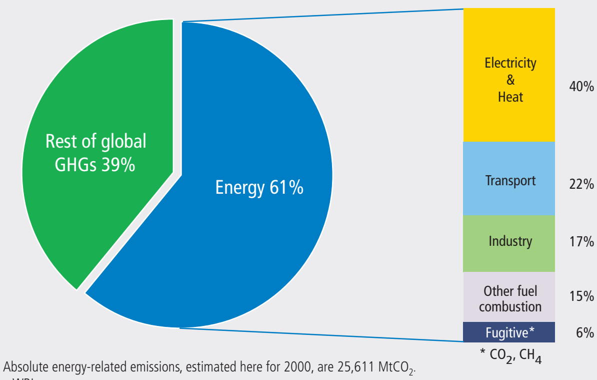
Energy delivery

An inefficient system

Supplying the world with energy produces 61% of the world's greenhouse gas emissions (see Fig. 4.3). This is the case because roughly 80% of the world's primary energy supply comes from the big-three fossil fuels: coal, oil, and natural gas. In addition to this, the energy delivery infrastructure is highly inefficient. According to official US energy statistics, more than 60% of the fuel energy used as an input is lost before it reaches the end user. There is also a significant amount of energy consumed during mining, extraction, and refining operations. These processing activities, plus flaring and venting of natural gas, contribute an estimated 7.7% to total global greenhouse gas emissions.

A shift in the energy mix toward natural gas, renewables, and nuclear energy (and away from coal and oil) will reduce the carbon intensity of energy. Energy delivery can also achieve a lower emissions trajectory through improved generation and transmission efficiency, reduced emissions from extraction and refining operations, and the development of carbon sequestration technologies. While greenhouse gas emissions from fossil fuel extraction and processing will likely increase as reserves become even more scarce, reduced natural gas flaring will prove beneficial. We will address each of these issues separately as we review the various energy delivery industries: electricity, oil & gas, nuclear, and renewables.

Fig. 4.3: Greenhouse gas emissions from energy



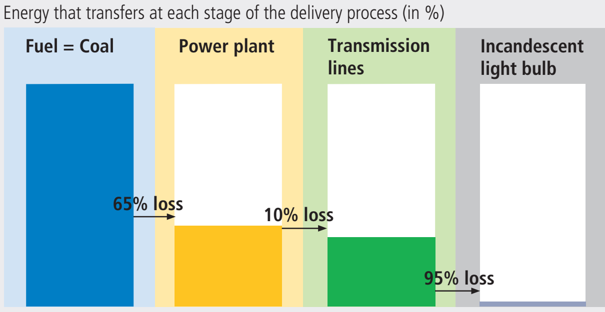
Note: Absolute energy-related emissions, estimated here for 2000, are 25,611 $MtCO_2$.
Source: WRI

Electricity inefficiency

The potential for energy efficiency in electricity generation is obvious in one of the most common energy lifecycles: transformation of coal's chemical energy to visible light using an incandescent electric bulb (see Fig. 4.4). Traditional utilities powered with fossil fuels transfer a little more than one third of the energy input into electricity. The majority is lost as heat. A centralized electricity system, with long transmission lines between power generation and application, sheds an additional 10% of the energy generated at the power plant. Lastly, transforming electricity into incandescent light results in a further 95% loss of the transmitted energy because most of the emitted energy is in the form of heat rather than visible light. Total energy captured to make visible light: 1.6%.

Fig. 4.4: Electricity inefficiency in the supply chain

Energy that transfers at each stage of the delivery process (in %)



Source: Sustainable Energy, Choosing Among Options (Tester, Drake, Driscoll, Golay, Peters)

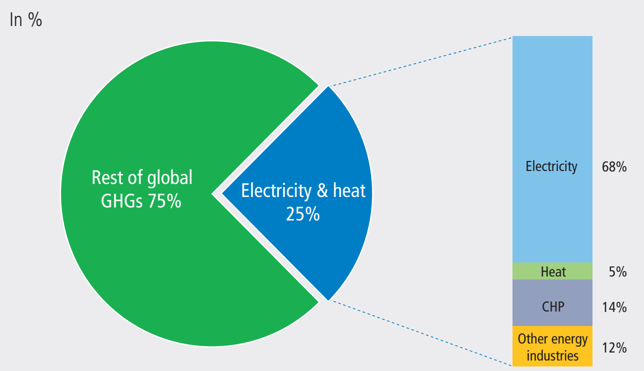
Electricity generation

Charged with the biggest emissions reductions
Because of its heavy fossil-fuel intensity, electricity and heat generation is responsible for about 25% of global greenhouse gas emissions (see Fig. 4.5). Coal is the single largest fuel source in electricity generation, followed by a roughly equal split between natural gas, nuclear, and hydro (see Fig. 4.6).

Based on a business-as-usual scenario, the IEA expects electricity production to double between 2004 and 2030, and for its share of final energy consumption to increase to 20% from 16%. With regard to trends in the underlying fuels involved in electricity production:
- Coal is projected to retain the largest share of electricity generation.
- Natural gas is projected to grow strongly in many world regions reflecting the increasing availability of the fuel and its clean burning attributes. Its share of electricity generation is expected to rise to 23% by 2030 from 21% in 2004.
- The share of nuclear power is projected to decline (see box on nuclear power on page 44). Capacity additions in developing countries and in economies in transition roughly balance the capacity being withdrawn in OECD countries. Few new nuclear power stations will be built in many countries without a change in existing government policies.
- Hydropower's contribution to electricity will likely remain roughly unchanged for the next quarter century.
- Renewables, which expanded substantially in absolute terms throughout the 1990s, are projected to grow six-fold through 2030. Renewables' share of OECD electricity generation will likely grow to 7% by 2030.

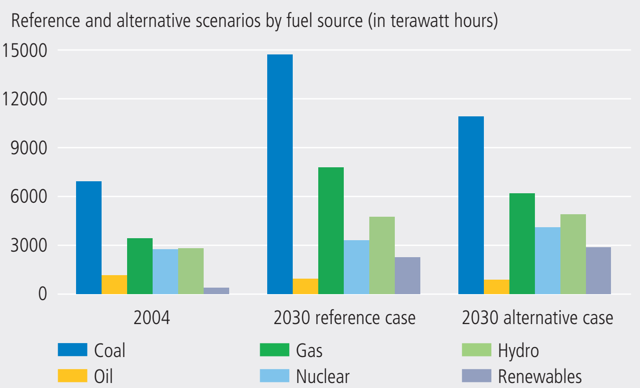
Without carbon sequestration, the expected increase in world electricity consumption in the coming decades, as well as the associated increase in fossil-fuel inputs, will lead to higher greenhouse gas emissions. The expected increase in renewable fuels and low carbon fossil fuels is insufficient for bringing about a lower path of greenhouse gas emissions, given overall electricity demand growth. Therefore, in order to just control the growth of emissions, power plants will need to:
- improve efficiency within the generation, distribution, and application channels;
- increase the use of fuel sources that are less carbon-intensive, such as natural gas; and
- more drastically increase the use of renewable energy, as well as pursue technological and efficiency gains in their use as a substitute fuel source.

Fig. 4.5: Greenhouse gas emissions from electricity & heat



Note: Absolute emissions in this sector, estimated here for 2000, are 10,269 Mt CO_2.
Source: WRI

Fig. 4.6: Projected world electricity generation



Source: International Energy Agency (2006)

Improved generation efficiency: Current coal-fired power plants operate at just above 30% efficiency. Technology exists for power plants to either channel their heat byproduct to local industries, institutions, and homes, or to use the heat as steam in a second-stage electricity generation process (that is, cogeneration or tri-generation). R&D plans for advanced gasification systems, target 60% efficiency by 2015.

Decentralize supply: The use of fossil fuels in electricity generation supports the development of large, centralized power plants, which are connected in a grid-based energy network through long power lines. Transmission of electricity over these long power lines results in a 10% energy loss and limits the reuse of heat for other applications. Expansion of cogeneration power plants are compatible with an increasingly decentralized electricity production system. Decentralized electricity generation allows for heat to be transported over shorter distances, closer proximity of the power plant to the end user, and improved transmission efficiency.

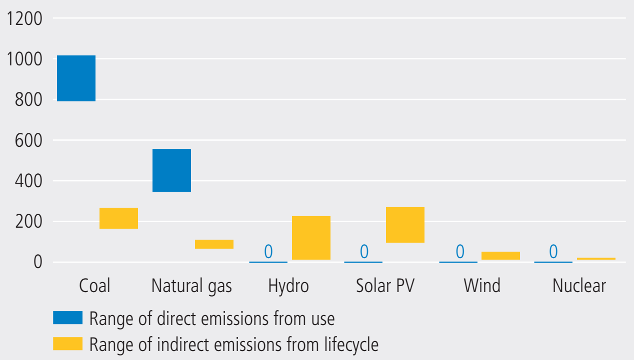
Switch in the fuel mix: One option to lower the carbon intensity of electricity production is to replace existing coal power generation facilities with natural gas-fired power plants, using combined cycle gas turbine technology. Because it produces fewer carbon dioxide emissions and burns more efficiently than coal, natural gas will likely become an increasingly important fuel source in electricity generation. However, substitution of natural gas for coal is not a foregone conclusion, as the decision would depend on fuel price developments, the price of carbon dioxide allowances, and wholesale power prices. High natural gas prices and low prices for carbon dioxide allowances would reduce the incentive for power companies to make this shift to natural gas (please see the appendix for a more thorough discussion of emissions allowances). Moreover, the long life cycle of power plants means that substitution is slow to occur. A more concerted focus on renewable fuel sources and nuclear energy will make a far larger contribution to containing the growth trajectory of greenhouse gas emissions in electricity production (see Fig. 4.7). Both of these are discussed in greater detail below.

Electricity regulation: Although there is much that electrical power utilities can do to reduce greenhouse gas emissions, the extent of switching and efficiency improvements in electricity generation depends on the effectiveness of the regulatory framework.

Subsidies: To encourage a reduction in the carbon intensity of electricity production requires a major overhaul of energy subsidies, so that policies tax electricity generated from fossil fuel inputs and redirect the revenues in the form of subsidies to renewable technologies. Subsidies of fossil fuel inputs lower the relative price of carbon-emitting energy sources. Such sub-

Fig. 4.7: Greenhouse gas emissions from electricity supply

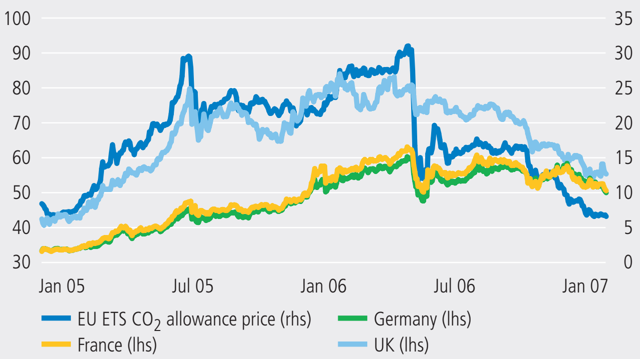
Range of direct and indirect emissions (in grams of carbon dioxide equivalent per kWh)



Source: International Atomic Energy Agency (2000)

Fig. 4.8: EU CO_2 allowance versus European power prices

In EUR/MWh In EUR per metric ton of carbon dioxide



Source: European Energy Exchange, Bloomberg sidies are still rather prevalent. In 2004, the European Environment Agency estimated that energy subsides in the EU-15 amounted to more than EUR 23.9 billion for solid fuels, such as oil and gas, and EUR 5.3 billion for renewable energy.

Access: Current electricity rules regarding power plant planning, certification, and grid access have been developed to favor large, centralized power plants, including extensive licensing requirements and specifications for access to the electrical grid. This favors existing large-scale electricity production and represents a market barrier to decentralized power distribution and more efficient power generation and transmission.

Carbon trading: As of 2006, the experience with the EU Emissions Trading Scheme shows that carbon trading has a direct effect on electrical power prices (see Fig. 4.8). By raising power prices, the EU ETS impacts the electrical utilities' investment decisions regarding future electricity generation. With a price assigned to carbon through emissions trading, electrical utility companies will likely increasingly invest to improve efficiency ratios, and will likely develop and implement new technologies to reduce emissions, such as clean coal (see box on clean coal on page 44).

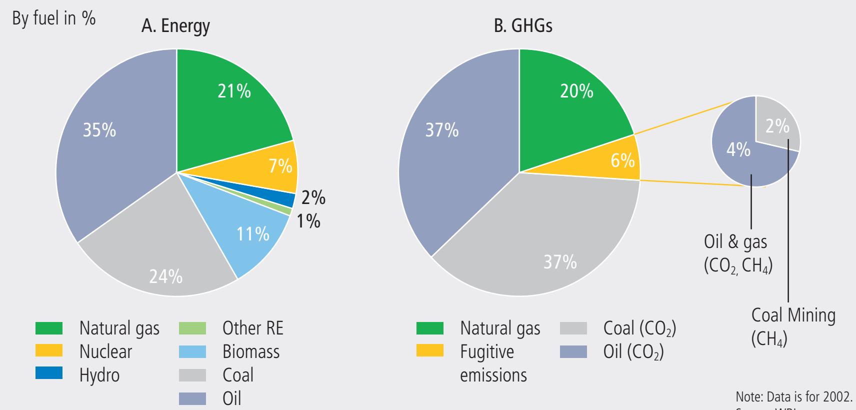
Oil and natural gas

No incentive to curb demand

Oil and natural gas consumption is responsible for 57% of global greenhouse gas emissions from energy use (see Fig. 4.9). Oil and gas extraction, refining, and processing emits an additional 6% of the world's greenhouse gases in the form of carbon dioxide and methane. However, the majority of greenhouse gas emissions are produced not in the mining and delivery of oil and natural gas, but rather in the burning.

Projected fossil fuel consumption, of which oil and natural gas represent a significant share, is far lower in the 2000 Watt scenario (see chapter 2) vision than the IEA reference and alternative scenarios. To lower greenhouse gas emissions in line with the 2000 Watt scenario requires a fundamental overhaul of the industries and products that demand and burn oil & natural gas. Otherwise, oil & natural gas companies will continue to supply the raw materials to meet their customers' demand. The oil & gas industry is concentrating efforts on raising production of cleaner-burning natural gas, and to a lesser extent, renewable energy sources, which will continue to erode demand for the industry's core products. That said, the industry is unlikely to be at the forefront of combating climate change, particularly since reform involves reduced consumption of its core products.

Fig. 4.9: World primary energy consumption and greenhouse gas emissions



Note: Data is for 2002.
Source: WRI

Coal: cleaning up its act

Clean coal technology refers to processes that improve coal plant efficiency and reduce emissions. Coal washing, which involves the removal of minerals and impurities before coal is burned, is standard practice in developed countries. Coal washing can reduce the ash content of coal by over 50%, leading to much lower particulate emissions, reduced sulfur dioxide emissions, and improved efficiency, which, in turn, leads to lower emissions of carbon dioxide. While this is standard practice in developed countries, it has yet to catch on widely in developing countries.

Emerging technologies in the design of coal-fired power plants will also further reduce emissions and improve efficiencies. Although not widely tested in commercial applications, combined cycle gas turbines hold the promise of greater power generation efficiency. For example, coal gasification techniques, employing the Integrated Gasification Combined Cycle approach, produce highly efficient electricity and gas for the transportation and chemical industries, but at a very high cost.

Another larger plan includes carbon capture and storage technology (see box on this subject on page 61). Further development work is necessary to improve energy efficiency and cost-effectiveness, as well as to better understand the environmental impact of storing carbon dioxide. Nevertheless, utility companies are currently investing in the development of such facilities. The first pilot plants are already in the construction phase.

Nuclear energy: fuel or foul?

In the past 30 years nuclear energy production capacity increased rapidly, and is now one of the major pillars of the world's electricity supply. In 2004, nuclear fuel contributed 16% to the world's electricity production and 6% to primary energy supply, according to the IEA. The threat of climate change and the rising cost of fossil fuels are factors that would be expected to increase the demand for nuclear electricity generation. However, as with all energy sources, nuclear power involves a complex trade-off between the advantages and disadvantages.

Benefits:
- After the initial investment is written off, nuclear power plants generate electricity at a lower cost than fossil fuel plants.
- Compared with thermal power stations that burn fossil fuels, nuclear power stations produce fewer carbon dioxide emissions, even after accounting for emissions from the mining and enrichment of uranium fuel.
- Uranium accounts for a far lower percentage of total energy production costs, only 3% to 5%, compared to fossil fuels, which in certain instances could run as high as 50%. This makes nuclear energy production costs more resistant to raw material cost fluctuations than fossil fuel energy.

Disadvantages:
- According to current estimates, known uranium deposits will suffice for 60 years at current production rates and power station capacity.
- A significant increase in nuclear energy production can only be achieved by using fast breeder technology, which increases the yield from the primary fuel by a factor of 60. However, this technology has not been able to establish itself in the mainstream during the past 30 years due to technological and financial difficulties.
- Radioactive waste needs to be safely stored for at least 100,000 years. Thus far, most countries have not managed to reach an agreement on where and how to deposit this waste.
- The threat of "new wars" (that is, not between nation states) increases the threat of nuclear terrorism. There is the risk that the knowledge related to nuclear power will be used for means other than electricity generation in the future.
- The heat from nuclear reactors is not widely suitable for combined heat and power, as the costs of heat conduction from big centralized reactor blocks are too high. This means that options for increased energy efficiency are limited.
- In several countries, nuclear power plants have a low public acceptance because of concerns about the potential for accidents.

Many countries have decided to increase their use of nuclear power. For example, the Chinese government intends to boost installed nuclear capacity to 40 gigawatts by 2020, or roughly 4% of overall generation capacity, from its 2005 capacity of about 7 gigawatts. New plant development is also progressing in India, Japan, Korea, some European countries, and the US.

This new construction is insufficient to offset the eventual decommissioning of existing nuclear power plants, the majority of which are more than 20 years old. In order to stabilize the amount of electricity generated with nuclear power plants in the future, an average of 11 new nuclear power plants would need to be built every year, with 66 power plants under construction at any one time (based on a construction time of six years and an average life of 40 years). Only 27 nuclear power plants are under construction worldwide. Although power plant operators can delay decommissioning, the current trend is that the absolute amount of electricity generated by nuclear power plants will decrease during the next several years.

Oil: According to the IEA's business-as-usual scenario, oil consumption will increase roughly 40% between 2004 and 2030. Keep in mind, however, that oil demand is not as tightly linked to changes in per capita economic growth rates as is overall energy demand, and therefore may not grow as strongly as projected. According to our UBS research focus, "Commodities: scarcity of abundance" (dated August 23, 2006) worldwide oil consumption will only grow 20% through 2025, largely because developed countries will continue to substitute other energy sources. In either case, oil demand forecasts stand in direct opposition to the 2000 Watt scenario, which would require outright reductions in oil consumption. Since most oil consumption is used in transportation (see transport section on page 50), emissions sequestration will prove difficult, placing the onus of reducing emissions on automotive redesign to accommodate low- and no-carbon fuels, and to improve efficiency.

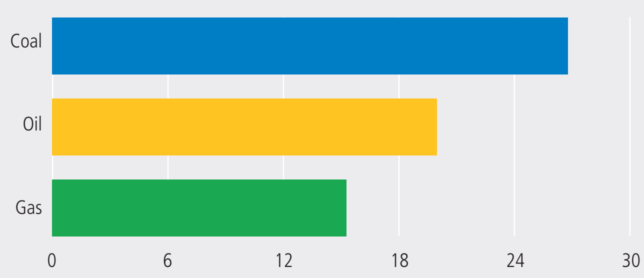
Besides the impact that the consumption of oil has on greenhouse gas concentrations and climate change risks, the oil industry faces an additional direct risk from climate change: business interruption from storm activity. Although the relationship between severe weather events and climate change is hotly debated in scientific and political circles, the relationship is evident enough for insurance companies and the oil industry to take notice. Hurricane Katrina, which hit Louisiana and Mississippi in late August 2005, interrupted oil production, imports, and refining operations in the Gulf of Mexico. Companies with oil exploration and production in hurricane-exposed areas are at particular risk, assuming that climate change raises the probability of severe weather conditions.

Natural gas: According to our UBS research focus, "Commodities: scarcity of abundance" (dated August 23, 2006), natural gas production will likely accelerate and eclipse oil production within the next quarter century. To the extent that it displaces oil and coal, this is a positive development from the perspective of greenhouse gas emissions. Depending on the technology used and the application, natural gas produces roughly 45% fewer carbon dioxide emissions than coal, and about 25% fewer carbon dioxide emissions than oil (see Fig. 4.10). This is due partly to lower carbon content and partly to the higher efficiency of combined-cycle gas turbines.

Increased use of natural gas as a percentage of primary energy is not the ultimate solution for reducing emissions. Just as with coal and oil, reducing emissions considerably involves reduced consumption. However, the industry can realize an opportunity to curb greenhouse gas emissions and generate additional revenue if it captures and sells natural gas byproducts from oil drilling.

Fig. 4.10: Carbon content of fossil fuels

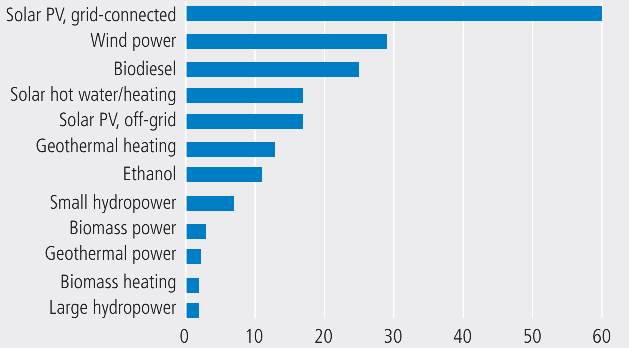
Tons of carbon per terajoule of energy



Note: The carbon emissions for coal is based on anthracite coal. There are slightly different carbon contents for other grades of coal, such as coking (25.8), bituminous (25.8), and lignite (27.6).
Source: WRI

Fig. 4.11: Strong growth in renewable energy capacity

Average annual growth rate (in %, 2000–04)



Source: Worldwatch Institute

Deregulation of the electricity generation industry will likely lead to higher natural gas demand. The IEA projects that the electrical power sector will account for more than half of the increase in global natural gas demand between 2004 and 2030. If carbon trading prices move higher, utilities will have an incentive to substitute natural gas for coal and oil in power generation, as it requires fewer emissions certificates.

On the one hand, greater regulation of climate change will likely increase the demand for natural gas. On the other hand, higher natural gas prices, which are linked to oil prices, make coal more cost-competitive for utilities. Therefore the price of carbon will have a significant impact on the fuel mix: high prices will favor low-emission natural gas, low prices will stimulate the demand for coal.

Impact of renewables: The shift to renewables will not only impact electricity production, but also oil and gas companies. Not all sources of renewable energy are relevant as a replacement for oil. Considering that nearly two-thirds of crude oil is used in transport, vehicle technology development is critical. Albeit at a very low level, bioethanol is beginning to displace gasoline (and biodiesel for diesel). Production efficiency improvements through second generation biofuel technology will likely provide further impetus (see section on biofuels on page 52). Oil and gas companies could use their competitive advantage within the existing refinery and fuel transport infrastructure, such as tankers and pipelines, to enter this market on a large scale.

Renewable energy

Demand growth requires dedicated policy
Renewables include biofuels, geothermal heat, hydropower, wind energy, solar energy (photovoltaic and solar thermal energy), traditional biomass, and wave power (see Fig 4.11). Consumption of new renewables (excluding traditional biomass and large hydro) accounts for a little more than 1% of total energy use according to the IEA. To effectively displace demand for fossil fuels and reduce greenhouse gas emissions, we calculate that renewable energy consumption will have to grow at roughly 11% per year for the next half century. This growth is almost twice the estimated annual growth rate projected in the IEA's reference scenario.

One of the primary benefits of renewables is that there are no carbon dioxide emissions from the conversion of the fuel input to energy, although there are sometimes indirect carbon dioxide emissions associated with producing the fuel source and the infrastructure (see Fig. 4.7). Another benefit of higher renewables use is that it would tend to reduce the volatility of energy costs. Fossil fuel prices are highly volatile. However, once a renewable energy source is brought into production, variable costs fluctuate only mildly. In addition, the relative price of fossil fuels may increase because of higher extraction costs and finite production limits, whereas further technological improvements and scaling effects for renewables will likely accelerate.

The optimal mix of renewable energy depends on the location. In some areas geothermal power is a popular and cost-effective alternative, in other areas big wind parks will provide the cheapest electric energy. Solar energy is a good choice for matching the energy needs of air conditioning systems. Ultimately, the choice of renewable energy will differ from region to region, depending on local conditions.

Renewables are receiving increased political support for their role in reducing dependence on fossil fuels and mitigating the risk of climate change. However, renewable energy development has not yet garnered widespread or systematic support. Eleven countries account for three-quarters of all renewable electricity production capacity (see Fig. 4.12). According to the Global Wind Energy Council, nearly 80% of the world's installed wind turbine generation capacity is located in just five countries. According to the Photovoltaic Power Systems Programme, over 70% of the world's photovoltaic energy is produced in Germany and Japan. In most countries, leaving aside the traditional use of biomass and hydropower, active use of renewables has barely taken its first steps.

New demand will help to lower costs and increase research to improve on current technologies. Guarded optimism for rapid global growth of renewables, excluding traditional biomass and hydro, is justified, however. Although increased political support for renewable energy gives it a strong chance for success, there is no clear indication that recent growth rates are self-sustaining. Keep in mind that renewable energy sources were all the rage in the early 1980s, only to be thrown aside when oil prices fell sharply and monetary policy aimed at containing inflation.

Energy delivery regulation

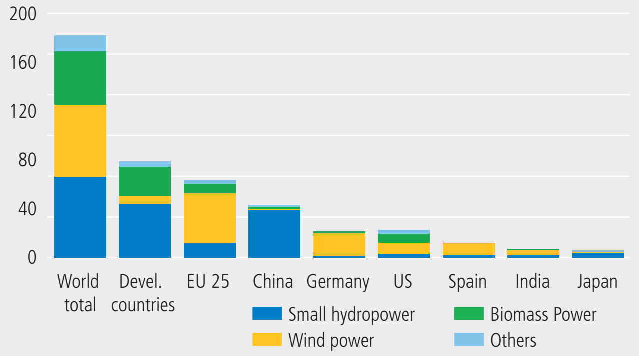
Regulation aimed at reducing the greenhouse gas emissions generated through energy delivery can either be focused on reducing the carbon intensity of fuels (that is, carbon dioxide emissions per unit of useful energy), changing the mix of fuels that are used to meet our energy demand, and reducing energy demand. Reducing the carbon intensity of different fuels has its limits, as the properties of the fuels cannot be significantly changed. Considerable changes on the supply side can be achieved in electricity generation. The introduction of the European Union Emissions Trading Scheme is a first step in this direction. So far emissions trading may have led to some efficiency gains, but it has not yet caused a significant switch from high-carbon to low-carbon fuels due to low carbon trading prices. Subsidies for renewable power in certain countries have proven to be very effective in increasing renewable power capacity. However, most policies with significant impact on energy delivery are steered from the demand side and will be discussed in the subsequent sections.

Summary of energy delivery

Energy delivery companies aim to distribute energy in one form or another at the cheapest possible cost to meet demand and earn a profit. Their focus is not on reducing greenhouse gas emissions. Even if it were their number one priority, it is unclear that the fossil fuel industries would be successful at creating a system that curbs emissions because such a goal involves curbing demand for their products. Increased use of renewables (partly supported

Fig. 4.12: Renewable electric power capacity

Excluding large hydro (in gigawatts, as of 2005)



Source: Renewable Energy Policy Network for the 21st Century by greater subsidies), more decentralized power plants, further support of nuclear power, energy contracting services, carbon sequestration, deregulation of electrical utilities, expansion of emissions trading, and improved capture and distribution of natural gas appear to be the likely outcomes in our analysis. While several developments support a reduction in the emissions intensity of energy production, outright emissions reductions from energy delivery activities, particularly below a base year of 1990, appear unlikely.

Therefore, public policy and regulation are necessary to contain greenhouse gas emissions, which result from energy delivery activities. Involving power utilities in emissions trading has the potential to further improve the cost competitiveness of low carbon and no carbon fuel sources, provided the allocation of the emissions allowances appropriately reflects the required level of emissions reductions. This effect could be supported by withdrawing subsidies for, and raising taxes on, fossil fuels to reflect a cost for carbon. Diverting these government revenues, in the form of subsidies, to develop renewable energy sources and efficiency enhancements would also provide financial backing for technologies that are currently in early stages of development.

Taking into account the growth projections for energy use, reducing greenhouse gas emissions to a level that stabilizes greenhouse gas concentrations will require outright reductions in the consumption of energy that is produced with fossil fuels. This is only possible with widespread demand-side changes, from outside the energy-generation industry.

Fig. 4.13: Summary table of energy delivery activities

	Business as usual	Steps to achieve the 2,000 Watt scenario
Producer and consumer behavior	Utilities offer increased, but still limited, access to renewable energy sources.	Consumers specifically ask for green power.
	Large centralized power plant development.	Smaller more decentralized power plants allow for combining heat and power.
Technology	Lack of coherent policies limit demand growth of renewable energy technologies.	Renewable energy technologies are competitive due to achieved cost reductions.
	High costs of clean coal technology limit adaptation.	Energy storage solutions are economically viable and allow for smooth electricity supply.
		Carbon sequestration becomes standard practice.
	First steps of coal gasification.	Full potential use of combined heat and power (including microturbines, fuel cells).
Regulation	Fossil fuel subsidies distort markets.	Fossil fuel subsidies are diverted to renewable energy sources.
	In the absence of carbon trading outside of Europe, high natural gas prices raise incentives for coal power plant development.	Price of carbon is high enough to make switch from coal to gas economically feasible.
	High natural gas prices and low carbon prices do not favor switch from coal to gas.	Increased use of demand-side policies.

Source: UBS

Food: eating petroleum

Food production is more globally interconnected than ever before and increasingly reliant on fossil fuel energy sources. Agriculture has always produced large amounts of greenhouse gas emissions through the release of methane, nitrous oxide, and carbon dioxide. However, because of higher energy intensity at all stages, the food production system has become an increasingly important contributor to greenhouse gas emissions (see Fig. 4.14).

Food travels further than ever. According to a study commissioned by the German Wuppertal Institute for Climate, Environment and Energy, the components and ingredients in a 240 ml cup of yogurt on a supermarket shelf in Berlin involved "food miles" of more than 9,000 kilometers of accumulated transportation. This is not an isolated case. In the US, a typical meal made of "in-season" produce travels 2,100 kilometers; add out-of-season produce and that number rises higher still. For the UK, it is estimated that agriculture and food account for about 30% of goods transported over roadways. More and more fresh food items coming from overseas are transported by air, which is one of the most energy- and greenhouse-gas-intensive forms of travel.

The industrialization of agriculture has lowered the energy return of food (joule output per joule input). Food is now often produced at large-scale, centrally-located facilities that use energy-intensive farming practices. This requires large amounts of fossil fuels for: farming machinery, fertilizers, and pesticides; food processing and distribution; and packaging materials. Transporting fresh products overseas by air, rather than sourcing them locally requires up to 50 times more fossil fuel energy. An air shipment of 1 kg of vegetables consumes 4 to 5 liters of petroleum, whereas the same amount of locally grown produce consumes about 0.1 to 0.3 liters.

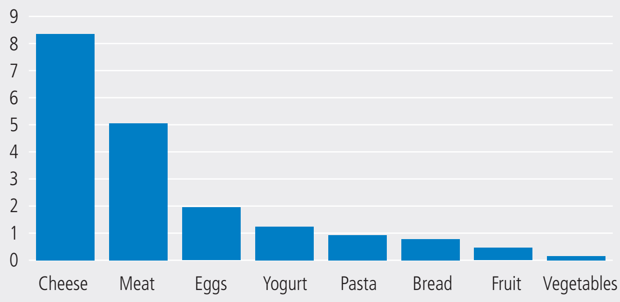
Many argue that buying foods grown locally is more environmentally friendly, as it eliminates the need for lengthy food transport. But are food products environmentally friendly simply because they are produced locally or regionally? The facts on this are rather ambiguous: certain products can be transported over long distances and still use less energy than a locally grown product. For example, it may require more energy to grow tomatoes in a cold environment than to transport them from regions where they are plentiful. The presence of agricultural and fuel subsidies, not to mention the lack of an airline fuel tax, distort the true cost of food on the shelves and enables highly traveled food items to appear cost competitive.

Labeling that shows the amount of energy involved in production and transport would make it easier for consumers to compare different products, help raise awareness of food miles, and provide an indicator of fuel used and related carbon dioxide emissions. Large supermarkets, with their centralized distribution systems, have contributed to the increase of food miles. Now they are increasingly addressing this issue, as consumers raise awareness. Some stores are providing more local sourcing and reducing overall fuel consumption for transport, but this trend is still in its infancy.

Ultimately, the relationship between the food we eat and the resulting greenhouse gas emissions is highly complex. The food miles associated with food production and distribution are important contributors to greenhouse gases, but so is the act of buying food. Increased local sourcing can help to lower the trajectory of greenhouse gas emissions, but is not the solution in all cases. What is certain is that driving to the store in a sport utility vehicle to purchase a single head of locally sourced organic lettuce can produce far more greenhouse gas emissions than are saved by switching away from lettuce grown further afield.

Fig. 4.14: Greenhouse gas emissions of selected foods

Carbon dioxide equivalent emissions per kilogram of product (in kilograms)



Source: Öko-Institut e.V.

Transportation

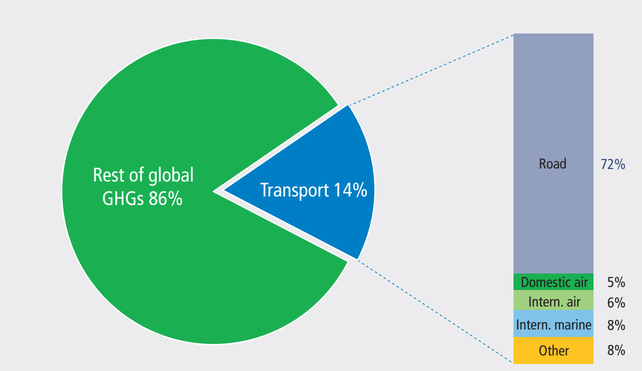
Emissions heading in the wrong direction
The transportation sector accounts for 14% of the world's total greenhouse gas emissions (see Fig. 4.15). All emissions from transport-related activities are in the form of carbon dioxide, and nearly all are tied to the sector's dependence on oil consumption (see Fig. 4.16). Road transport accounts for about three quarters of the energy use in transportation, followed by the rapidly growing air transport segment (see Fig. 4.17). Therefore, changes to energy consumption within the automotive and airline sectors will likely dictate how transportation activities influence emissions.

The IEA projects a 1.8% average annual increase in energy demand within the transport sector, largely driven by transportation demand growth in developing countries. Increased globalization, just-in-time and supply-on-demand deliveries, as well as expansion of large urban regions, will likely contribute to this trend. Furthermore, lower vehicle occupancy rates produce higher traffic volumes. Outside of energy delivery, transportation-related activities will likely produce one of the fastest growth rates in overall greenhouse gas emissions during at least the next quarter century (see Fig. 4.18).

That said, changes in transportation activities can yield large reductions in greenhouse gas intensity and gains in energy efficiency in a relatively short period of time, since the average lifespan of most cars is roughly 10 to 12 years. These gains can be achieved through changes in the vehicle itself, such as with lighter-weight materials and improved engine technology, as well as with new fuel inputs. The use of renewable fuels and fuels with lower carbon content, such as biofuels, natural gas, and hydrogen, have the potential to reduce carbon dioxide emissions over the whole transportation equipment life cycle. Shifts in modality, such as from air to rail, also hold the promise for reduced emissions in transport (see Fig. 4.19).

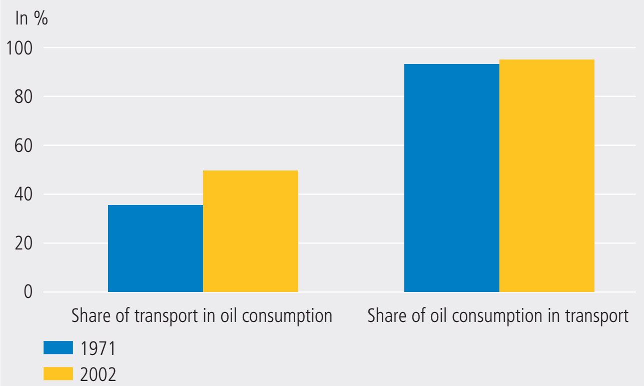
Infrastructure development to improve inter-modality, rather than to enlarge the transport network, will produce large long-term energy savings. Such investment allows public transport by rail to become a better substitute for private cars and short-distance air travel. Improved infrastructure technology and information technology can reduce traffic jams (cars) and queuing (air), help to avoid detours, and improve fuel efficiency. Lastly, there is a clear correlation between highway speed and fuel use. Reduced speeds can cut emissions by lowering fuel use. According to the German Federal Environment Agency (2003), reducing automotive speed on federal motorways to 100 kilometers per hour could lower automotive energy consumption by 10% to 20%, and would create an incentive to use alternate modes of public transport, such as high-speed rail, to reduce travel times.

Fig. 4.15: Greenhouse gas emissions from transportation



Note: Absolute emissions in this sector, estimated here for 2000, are 15,743 Mt CO_2.
Source: WRI

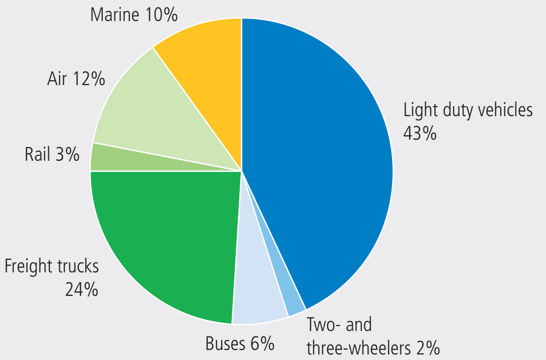
Fig. 4.16: Strong link between oil demand and transport



Source: International Energy Agency (2004)

Fig. 4.17: Road vehicles dominate transport energy

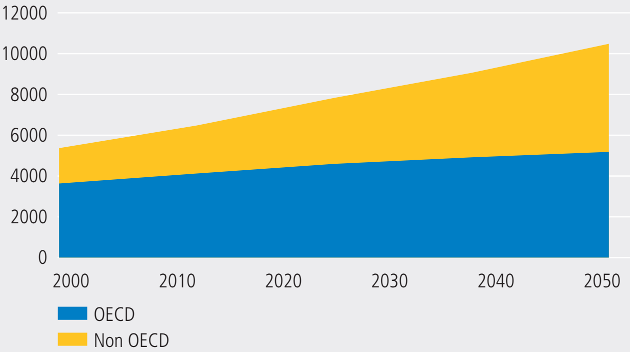
World transport energy use by mode, all fuels (2000, in %)



Source: World Business Council for Sustainable Development

Fig. 4.18: Projected transport-related CO_2 emissions

By region (in million metric tons of carbon dioxide)



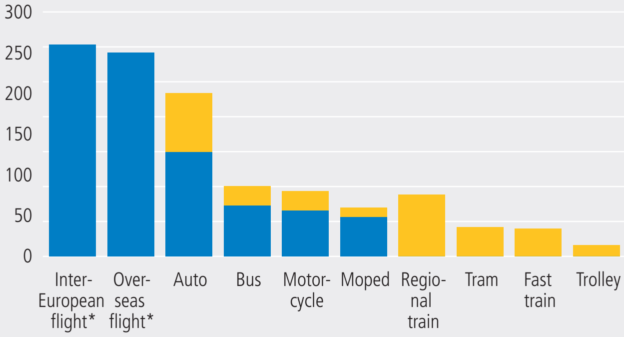
Source: World Business Council for Sustainable Development, Sustainable Mobility Project

Lightweight composite materials

The energy required to move an object is directly related to the object's weight. For years, the aviation and aerospace industries have been driving forces behind lightweight innovations in transport. For example, the airline industry has a high incentive to reduce fleet weight per passenger mile, as fuel costs are a considerable part of airline operating expenses. The same is not true in the auto industry where the average weight of a passenger car has increased by about 30% in the last 15 years. Weight improvements in car construction are often dwarfed by the added heft of safety and comfort features. However, high energy prices and tightening climate change regulations will likely raise the importance of reducing vehicle weight for the entire transportation industry, in our view.

Fig. 4.19: Greenhouse gas emissions from transportation

Grams per passenger and kilometer



Source: Maibach et al. (1997)

Note: * = combined direct and indirect

Many different materials are used to replace traditional heavy steel and cast iron components. One option involves the use of lighter metals, such as aluminum, magnesium, and titanium. Another option involves advanced composites. Composites consist of two or more materials that are combined to make a new material, whose properties cannot be predicted by simply summing the properties of the original component materials. Advanced composites are high-value, high-performance materials that utilize a combination of resins and fibers, customarily carbon/graphite, Kevlar, or fiberglass with an epoxy resin. This combination offers a range of benefits: advanced composites are more durable and lighter than metals; they can be molded into complex shapes; they have a higher fatigue endurance limit; and they do not corrode.

Carbon fiber has already made its way to the mass market for sporting goods. Ten years ago, carbon fiber racing boats, fishing rods, and ski poles were reserved for the luxury class. Now they have become standard items. Carbon fiber weighs one-fifth as much as steel yet is equally durable, making it ideal for structural or semi-structural components in automobiles. It is also highly shock absorbent and hence very safe. Intelligent lightweight construction can reduce a vehicle's weight by as much as 60%, leading to a reduction of fuel consumption of at least 30%, as smaller engines could be used with lighter vehicles. Although carbon fiber composites are very expensive and cost at least 20 times as much as steel on a weight basis, cars would need far less carbon fiber than steel. In the end, what counts is not the "cost per kilogram," but the "cost per car."

While carbon fiber technology is used in high performance applications, such as aerospace and racing cars, the product has not yet reached the transportation mass market. Carbon fiber has high potential for contributing to reduced greenhouse gases through lighter weight vehicles. However, it can only become a truly competitive and sustainable solution in conjunction with revolutionary technologies and concepts, such as cars made from "one mold." Such concepts are not based on "part by part" replacement of heavier components with carbon fiber, but require innovative design and completely new, simplified production processes. Cost is the major obstacle for bringing carbon fiber to the mass market. New capacity is being added, and improved production processes will contribute to further cost savings.

To get a glimpse of where lightweight technology is headed, look to the pioneers of high-performance materials in cars: Formula 1 and NASCAR. History has shown that many innovative technologies pioneered in auto racing have become mass-market standards in just one or two decades (for example, ABS, traction control, computer-based engine management systems). Carbon fiber is now the standard in auto racing, which may be a precursor to its eventual adoption in mainstream automaking.

Biofuels

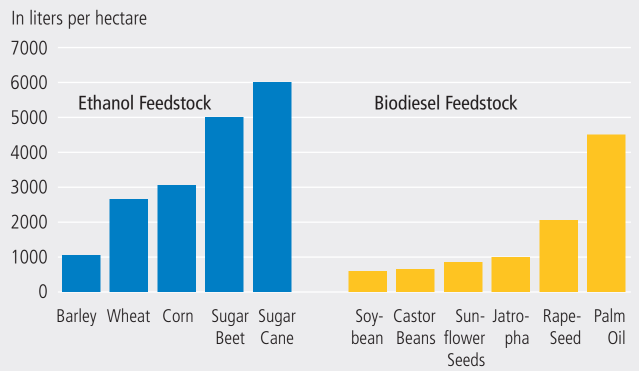
Are they just another pipe dream?
Reducing transportation-related greenhouse gas emissions is unlikely without advances to displace gasoline and diesel and replace them with biofuels, such as bioethanol and biodiesel. Although biofuel production involves consumption of fossil fuels at various stages of the production process, the main ingredients of biofuels are largely carbon neutral. In essence, growing plant biomass absorbs as much carbon dioxide as it emits when combusted. Current technology for producing biofuels is insufficient to meet the enormous energy demands of the transportation infrastructure. New technology to reduce the fossil fuel intensity of biofuels is on the horizon, but not yet available in a cost-competitive form.

Bioethanol is the most widely-produced biofuel, with a production of more than 35 billion liters in 2005. It is an alcohol-based fuel made from a variety of renewable feedstocks, such as sugar, starch, and cellulose (see Fig. 4.20). The world's largest bioethanol producers are Brazil and the US. In the US, bioethanol is typically produced from corn, whereas sugar cane is the preferred feedstock in Brazil. Bioethanol is made when carbohydrates are converted into sugars, which are then fermented in a process similar to brewing beer, before going through a distillation process. The resulting liquid fuel is then distributed through existing petrol stations. Bioethanol is usually blended with gasoline in varying quantities: two common mixtures are E10 and E85, which contain 10% and 85% bioethanol, respectively. Most cars in circulation today will operate on E10, while E85 is used in flexible fuel vehicles, which are capable of operating with higher concentrations of bioethanol.

Biodiesel production amounted to around 3.5 billion liters in 2005. The fuel is produced through a chemical process that combines organically derived oils and alcohol to form a chemical reaction. Biodiesel can be made from soybean and canola (rape seed) oils, animal fats, and waste vegetable oils, and is a combustible fuel that is physically similar to petroleum-derived diesel (see Fig. 4.20). The EU accounted for nearly 90 percent of all biodiesel production worldwide in 2005.

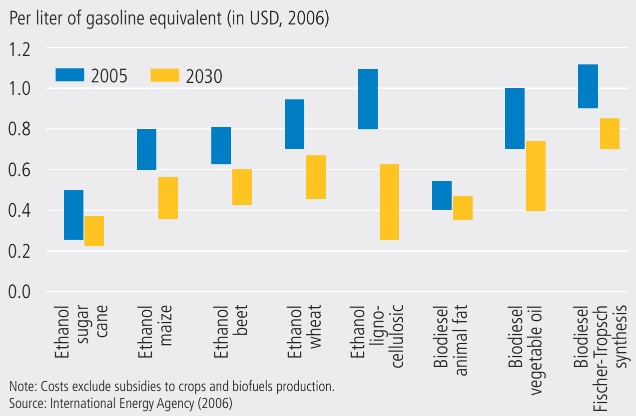
Whether biofuels become a major energy source or not depends primarily on technology development, but also on the tax regime, local government subsidies, and the presence of trade restrictions. Some types of bioethanol and biodiesel are more expensive to produce than traditional gasoline and diesel, requiring either an increase in traditional fuel costs or government subsidies and tax advantages to remain competitive (see Fig. 4.21). Because of favorable climate circumstances (more sunlight for photosynthesis) and

Fig. 4.20: Biofuel yields of selected feedstocks



Source: International Energy Agency (2004), Worldwatch Institute (2006)

Fig. 4.21: Cost ranges for ethanol production



Note: Costs exclude subsidies to crops and biofuels production.
Source: International Energy Agency (2006)

relatively low production costs, the growth potential for producing biofuels in tropical and subtropical areas is large, particularly if barriers to international trade in biofuels are lowered. Brazil produces ethanol from sugar at less than half the cost of EU-based ethanol.

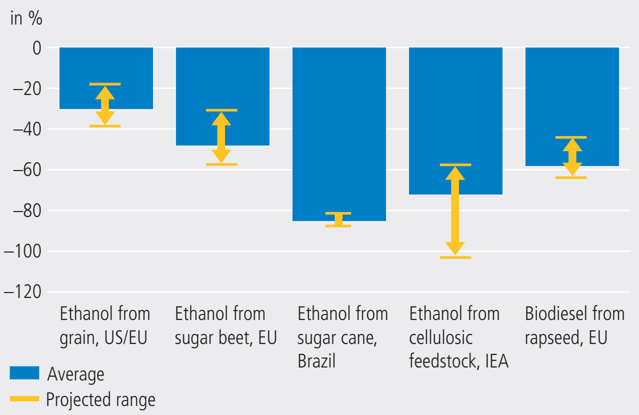
Biofuel production in its present form competes with food production and encourages the conversion of tropical and subtropical forests to agricultural use. The percentage of total US corn acreage dedicated to bioethanol increased to around 15% in 2005 from 5% in 2000, with forecasts for this to exceed 20% soon. Rising demand for biofuels is increasingly linking prices for traditional food crops, such as corn, wheat, and sugar, with energy prices. Because of limited arable land resources, a strong expansion of biofuels using current state-of-the-art technology has its limits. In an extreme case, clearing forests to bring additional arable land into crop production would offset the original benefit of using biofuels. Overall, the current production of biofuels is not the ultimate answer for a sustainable transport system, particularly given the price incentives to farm fragile ecosystems.

The biofuel potential

Thanks to large efficiency gains, biofuels generally contain more useful energy than is required to produce them. The actual net greenhouse gas reduction depends on different factors, including manufacturing processes, use of residual input materials from production, and the type of crop. Sugar cane produces far higher emissions reductions than sugar beets or grains. Looking to second-generation technology, cellulosic feedstocks (for example, switchgrass, poplar) have the highest estimated potential to reduce greenhouse gas emissions (see Fig. 4.22).

Whereas current biofuel production uses only part of a plant (for example, oil, sugar, and starch), second generation biofuels based on biomass-to-liquid technology will use the whole plant (that is, cellulose) to produce fuel, thereby increasing the variety of possible feedstocks. The application of such new technologies could lead to a fundamental reevaluation of biofuels, as they will strongly improve their environmental and social footprint. Biomass resources, such as the waste from agriculture, forestry, and municipal facilities, as well as non-food perennial crops, such as switchgrass, would reduce the negative environmental and social impact of biofuel production and reduce production costs. These positive features would also improve the greenhouse gas reduction potential, and would reduce the dependency on agriculture.

Fig. 4.22: Range of estimated greenhouse gas reductions



Note: This figure shows reductions in well-to-wheels carbon-dioxide-equivalent greenhouse gas emissions per kilometer from various biofuel/feedstock combinations, compared to conventional-fuelled vehicles. Ethanol is compared to gasoline vehicles and biodiesel to diesel vehicles. Blends provide proportional reductions (e.g., a 10% ethanol blend would provide reductions one-tenth those shown here. Vertical lines indicate range of estimates.

Source: International Energy Agency (2004)

This technology will take several years to develop into a viable industry, as converting cellulose to bioethanol is both technically difficult and expensive (see Fig. 4.23). Government funding could accelerate the transition to this new technology; however, a commercially viable form of cellulosic ethanol is still several years off. Government involvement in biofuels production is gathering momentum, primarily in the form of targets for displacing gasoline and diesel consumption. For example, the EU aims to increase the proportion of biofuels to 5.75% of all petrol and diesel used in transport by 2010 and to 20% by 2020. The US aims to double consumption of bioethanol to at least 28.4 billion liters annually by 2012, and E10 blended gasoline is now mandatory in five Chinese provinces, which account for 16% of all passenger traffic volume.

Presuming cellulosic biofuel becomes a cost-competitive technology, renewable energy will radically alter the transportation landscape. It will allow the world economy to become less dependent on key oil producing nations, hence reducing the risk of geopolitical disruption. Enhanced biofuel production, combined with measures to raise vehicle fuel efficiency, offers enormous potential for reducing greenhouse gas emissions in road transport.

Automotive

Overhaul vehicle design

Road transport is responsible for nearly three-quarters of the greenhouse gas emissions from transportation-related activities. Although the auto industry has a high indirect exposure to greenhouse gas emissions, little progress has been made to improve energy efficiency since the gains made in the early 1980s. Even self-imposed carbon dioxide emissions restrictions appear ambitious. The European Automobile Manufacturers Association (ACEA) set a reduction target for all new cars of 140 g/km by 2008. The target translates to an average fuel consumption of 5–6 liters per 100 kilometers. The EU projected 120 g/km by 2012. Although certainly declining during the past decade, average carbon dioxide emissions of new European cars still stood at 164 g/km in 2003 (see Fig. 4.24).

Growth in miles traveled and the number of cars on the road far surpass the progress in reducing vehicle emissions intensity. Demand for cars, particularly in developing countries, will likely continue to outpace efficiency gains, leading to continued growth in greenhouse gas emissions from road transport.

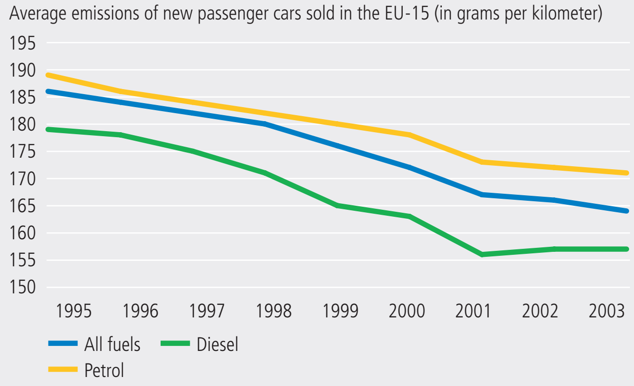
There are numerous opportunities for reducing greenhouse gas emissions within the auto industry. Automakers can reduce the engine size and can also reduce vehicle weight. Ever-increasing safety standards and comfort equipment have increased vehicle weight, which, in turn, increases fuel

Fig. 4.23: Summary of biofuels

Benefits	Disadvantages
Improved energy security if it is able to reduce dependence on oil imports.	Raw fuel-source material production often based on monocultures; high amount of land needed.
Use within existing infrastructure, mixable with conventional fuels.	Higher fuel production costs for the time being.
	Competes with food production.
High efficiency potential due to new technologies and wider variety of feed-stocks; cost reduction potential is high.	Competes with the production of biomass-based electricity and heat, where the eco-balance is significantly better.
Lower levels of most air pollutants, lower greenhouse gas emissions.	Production expansion in emerging and developing countries may endanger environmental and social minimum standards, issue of biofuel plantations and biofuel production on ecologically fragile lands.
New opportunities for farmers (energy farming).	Risks to biodiversity due to genetically modified organism (GMO) seeds.

Source: UBS

Fig. 4.24: Slow improvement in carbon dioxide emissions



Source: EEA (2006)

consumption. However, reinforced materials and alloy space frame bodies with high energy absorption would provide protection in the case of an accident and would also help to lower weight. A 10% reduction in automobile weight produces a 5% to 7% improvement in fuel efficiency, provided that engine performance is adjusted downwards to the lower vehicle weight (see box on lightweight materials on page 51).

Advances in internal combustion engines, powertrain development, start-stop alternators, braking energy recuperation systems, and more efficient tires represent the primary technologies for reducing carbon dioxide emissions from road transport. New engines and powertrains will accelerate the growth of renewable fuels and hold tremendous potential for carbon dioxide emission reductions. There is still some room for an estimated 10% to 20% efficiency improvement in traditional gasoline combustion engines. The current fleet of diesel vehicles is more fuel efficient than gasoline-powered vehicles and produces about 10% fewer carbon dioxide emissions (see Fig. 4.25).

Trends in powertrains
The traditional internal combustion engine (whether gasoline, diesel or hybrid) will likely remain the powertrain of choice, particularly as it allows for a switch to bioethanol and biodiesel. We expect a strong increase in alternative fuel use, but from a very low base.

Hybrid engines improve vehicle fuel efficiency and reduce emissions, especially in urban and congested areas. However, the technology also has its shortcomings. The advantages in suburbs or driving at full speed on highways are very limited. The vehicles are heavier, require more energy and resources in production, incur higher production costs, and raise important battery recycling considerations. Hybrids offer the greatest fuel economy when they replace large and high fuel consuming SUVs and pick-up trucks. Diesel hybrids produce additional fuel savings, although small diesel-powered cars are already more fuel efficient than gas-powered vehicles. Whether diesel or gasoline powered, hybrids cost more than traditional powertrains. Moreover, the improved fuel efficiency is questionable, since buyers are often more interested in gaining additional power and torque for the same fuel input. Given the higher overall costs, we believe hybrids will only achieve a market share of 5% to 10%, with a lower share in Europe and a higher share in the US.

In our view, hybrids are only an intermediate technology to fuel cells, which transform hydrogen and oxygen into electricity to propel an electric engine with zero tailpipe emissions of carbon dioxide. However, emissions are only truly reduced over the whole lifecycle, if the hydrogen can be produced with electricity generated from renewable sources. Combined with regenerative braking power to recharge an on-board battery, it offers a true environmentally friendly transportation solution. Government policies continue to favor traditional powertrains over new engine technology. Therefore, to ensure the development of fuel cell technology, government support of fuel cells or withdrawing policies that support polluting technologies is necessary. Hydrogen-powered fuel cell vehicles are not yet commercially available. We believe that it will take at least ten to fifteen years before full cell powered vehicles are launched in large numbers.

Aviation

Improved energy efficiency options
Domestic and international aviation accounts for roughly 1.6% of the world's greenhouse gas emissions and 12% of carbon dioxide emissions from transport. Despite these rather small figures, the impact of air travel on climate change may be higher than the overall amount of carbon diox-

Fig. 4.25: Potential of conventional technologies

Percentage carbon dioxide reduction potential (in %) and cost (in EUR)

Measure	CO_2 reduction potential (%)	Additional costs (EUR)
Fuels		
Roll-on-tires	3–5	0–20
Low-viscosity oil	1–5	0–30
Engine		
Petrol direct injection, incl. exhaust recirculation	10–13	150–200
Variable valve timing and electromechanical valve actuation	15–20	240–470
Downsizing/turbocharger	5–7	200–270
Transmission		
Automated gearshift	3–5	
6-speed automatic transmission	1–3	170–340
Variable transmission	5–10	85–340
Weight reduction		
Aluminum	5–8	0–375
Plastics	5–8	60–1800
Propulsion system		
Diesel-powered vs. petrol engine	8–13	150–620
Start/stop function, mild hybrid	8–10	800–960
Summary		
Petrol engine with direct injection	35–49	230–1320
Diesel engine with direct injection	23–41	240–1360

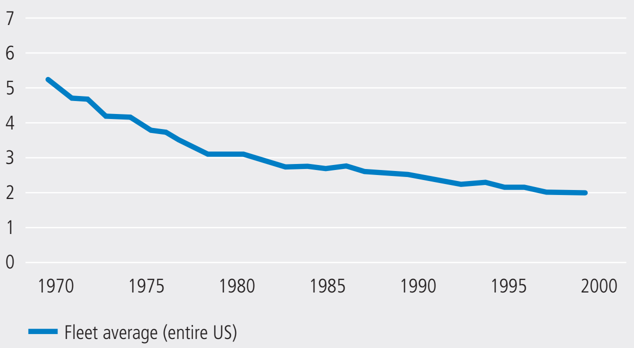
Sources: WestLB Research, Kolke, National Research Council

ide emissions would suggest: high-altitude release of water vapor, nitrous oxide emissions, and condensation trails all increase the estimated impact of air travel on the world's climate. The only potential methods for the airline industry to reduce its impact on greenhouse gas emissions are through improved energy efficiency and reduced fuel use. However, policy options that incorporate the cost of carbon into the cost of air travel would also serve as a potential demand-side measure to reduce emissions.

The energy efficiency of airplanes has improved steadily, largely thanks to the effect that composite materials have had on increasing plane size and improving wing design (see Fig. 4.26). Technical development will take another leap forward with the introduction of the latest models, which boast a 15% lower cost per passenger mile because of reduced fuel costs, improved operational efficiency, and lighter weight per passenger.

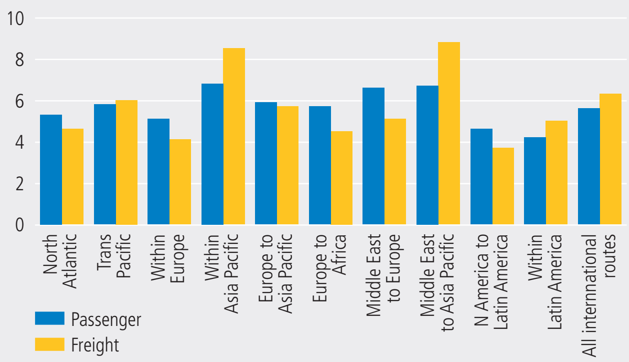
Nevertheless, growth in passenger traffic is overwhelming any efficiency gains. Historically, the increase in passenger miles flown has typically amounted to twice the growth of GDP. The International Air Transport Association (IATA) estimates an annual passenger traffic growth of 5.6%

Fig. 4.26: Fuel efficiency for commercial aircraft



Source: Waitz et al. (2005)

Fig. 4.27: Annual traffic growth expectations



Source: International Air Transport Association from 2005 to 2009 (see Fig. 4.27). The group also forecasts air freight growth of 6.3%, reflecting the growing distance between production sites and final consumption. Looking further ahead, air travel will likely become more affordable for people in developing countries, which will likely support continued high growth rates in air travel.

There is no alternative to kerosene for the foreseeable future. Replacing hydrocarbons with other energy sources appears unlikely. First, heightened security measures would not allow for the use of hydrogen, which is a highly-reactive fuel. Images of the Hindenburg in Lakehurst had a lasting impact. Second, weight is an important factor in flight, and the pressurized containment needed for hydrogen or natural gas is far too heavy to be feasible. Very lightweight planes can be powered by solar cells alone, but their use is restricted to one person or a small group of people, they offer limited comfort, and have a restricted scope of use, which does not allow for scheduled service.

Aviation regulation
The only potential option for reducing greenhouse gas emissions considerably in the air transport sector is to increase the cost of air travel sufficiently to curb demand. Given that air traffic acts to stimulate economic activity by allowing for business travel and tourism, political support for internalizing carbon emissions in the price of air travel remains questionable. To a large extent, air travel is taking place between different countries, and therefore requires at least regional, and ideally global, greenhouse gas containment efforts. Yet there is no commitment to reduce aviation emissions within the Kyoto Protocol because of difficulties with attributing emissions to a particular country. A motion for a European Parliament Resolution submitted in June 2006 requests the introduction of kerosene taxes, and taxes on all domestic and intra-EU flights as steps to internalize the costs of carbon dioxide emissions. The motion also calls for research into the effects of aircraft contrails and aerosols in the stratosphere. Inclusion in an emissions trading scheme would prove difficult, but would need to be a target if emissions from air transport are to be reduced.

Transport regulation

Unlike some activities that produce large quantities of concentrated point-source emissions, such as cement and steel manufacturing, transportation emissions are the byproduct of a widely dispersed fleet of numerous, small, inefficient, fossil-fuel-burning engines. Hence, regulation aimed at reducing greenhouse gas emissions from transportation can either focus on improving transportation technology or on influencing transport demand.

On the technology side, options include mandatory automobile fuel economy standards, which exist in several Asian countries and the US, or technology mandates, such as California's zero-emission vehicle standards. So far, such standards have produced roughly 1% to 2% efficiency gains per year. Targets to increase the use of biofuels in transportation (for example, in the EU and the US) are making further small contributions to reduce greenhouse gas emissions.

There exists very little regulation to strongly influence transportation demand, and the incentives that are in place are not always consistent or efficient. Users of roads rarely pay directly for infrastructure costs; these costs are typically paid indirectly through taxation. Airline fuel is tax free, whereas automotive gasoline is routinely taxed (sometimes to pay for transport infrastructure). Meanwhile, railroads are often forced to rely on subsidies for operational support and equipment upgrades.

Summary of transportation

The transportation industry will continue to pursue incremental steps to improve the energy-efficiency of travel to reduce operating costs and build a competitive sales advantage through hybrids, fuel cells and flexible fuel vehicles. For these efforts to succeed in producing actual emissions reductions, efficiency measures will have to advance at a faster pace than demand for transportation-related activities. Certain hybrid vehicles operate at twice the efficiency of internal combustion engines. However, the technology is expensive and likely beyond the reach of most developing country consumers. Hybrid producers will continue to pass along cost reductions, economies of scale, and improved efficiencies, as more competition becomes available. Without further regulation, airline emissions look poised to accelerate in most reasonable scenarios, as demand will likely outstrip efficiency gains.

Persistently high energy prices may increase demand for more fuel-efficient vehicles and public transportation. Current regulation in transportation is mainly aimed at technology improvements, but historically this has only brought about energy efficiency gains of between 1% and 2% per year. Ultimately, improvements in efficiency have to be larger than the growth in transportation activities to yield actual reductions in greenhouse gas emissions. To compensate for annual growth in transportation demand of a little more than 2%, automotive efficiency would have to improve around 4% every year for several decades in order to achieve a 2,000 Watt scenario. For aviation, where growth is even larger, efficiency would have to increase at least 6% every year. Whether it makes more sense to dramatically improve efficiency or to reduce demand, either outcome is unlikely without a policy framework that considerably changes the vehicle fleet and travel consumption incentives. Such policies would include minimum fuel efficiency standards and emissions taxes based on vehicle weight, miles traveled, and engine efficiency.

The fact that most vehicles are mass produced, use the same propulsion technology (that is, the internal combustion engine or jet engine), and are powered predominantly by the same fuels (gasoline and diesel or kerosene) makes the industry more easily regulated. Effective policies will raise the cost of fossil fuel sources used in transport, reduce the growth rate of overall transport demand, and channel demand away from transport that is heavily fossil-fuel dependent and towards transport that is both more energy efficient and reliant on renewable energy sources.

Fig. 4.28: Summary table of transportation activities

	Business as usual	Steps to achieve the 2,000 Watt scenario
Consumer behavior	Preference for space, horsepower, and special features in cars a higher priority than fuel efficiency.	Fuel efficiency is key buying criterion for cars.
		Increased use of video conferences, local tourism, and rail travel; provision of adequate public transportation services.
	Airline and car demand grows as projected.	Less demand for commuting due to improved spatial planning.
Technology	Incremental energy efficiency improvements in different modes of transportation technology of 1–2% per year.	Energy efficiency improvements in different modes of transportation technology between 4–5% through revolutionary vehicle concepts; car weight is reduced by at least 60%.
	Gains in fuel efficiency are to a large part overcompensated by technology and luxury, and safety features.	Fuel cell technology breakthrough.
		Second generation biofuel technology becomes both viable and cost competitive.
Regulation	Few incentives to influence demand side of transportation.	Airline fuel taxes are incorporated into freight and passenger flight costs.
	Rail connected inter-modality remains only a vision, and not a reality.	Emission taxes based on vehicle use, size and fuel efficiency.

Source: UBS

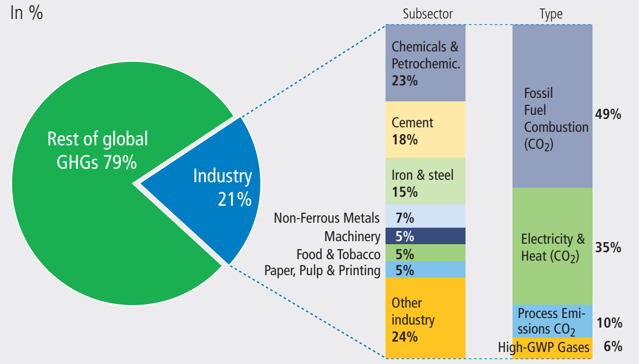
Industrial processes and material use

Industrial emissions
Industrial manufacturing activities account for just over one-fifth of greenhouse gas emissions (see Fig. 4.29). The primary production processes that account for these emissions include: chemicals and petrochemicals, cement and steel manufacturing, and the production of machinery. Whereas transportation activities mainly produce carbon dioxide emissions, the industrial sector is responsible for a wider range of greenhouse gas emissions, including carbon dioxide, methane, and gases with some of the highest global warming potential, such as hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride. Whereas transportation activities involve numerous, small point sources, industrial process emissions emanate from a relatively small number of large point sources.

While greenhouse gas emissions from industrial processes and materials use are expected to grow more slowly than for other activities, such emissions will increasingly originate in developing countries. This is the case because of strong economic growth rates in many developing countries, as well as a relocation of manufacturing and industrial operations out of developed countries to areas with lower labor cost structures and efficient centers of production. Meanwhile, developed countries have already made considerable progress in reducing the emissions intensity of industrial activities through improved energy efficiency. This dynamic makes policy considerations exceedingly complicated because:
1. an uneven policy framework could prompt companies to relocate production centers to countries with more relaxed environmental rules,
2. many industrial activities provide the foundation for global economic growth and cannot be easily curtailed, such as steel and cement production,
3. production centers are increasingly located in developing countries, which are not obligated to reduce emissions under the Kyoto Protocol, and
4. developing countries have the highest potential to reduce emissions intensity in industrial processes.

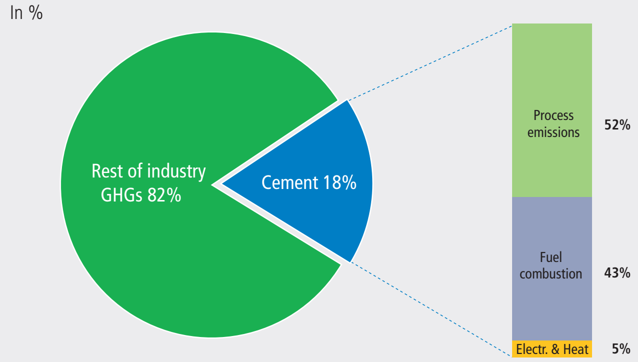
Large equipment and industrial plants are built to last throughout a long lifecycle, leading to the slow adoption of new technologies. That said, any production process can be made instantly obsolete if there is a new breakthrough/disruptive technology that leads to radical changes in how things are done. The wide array of processes and products involved in industrial and materials production makes it difficult to generalize about how to bring about greenhouse gas emissions reductions. However, solutions for process improvements and materials efficiency can be grouped into the following categories:

Fig. 4.29: Greenhouse gases from industry



Note: Absolute emissions in this sector, estimated here for 2000, are 8,856 Mt CO_2.
Source: WRI

Fig. 4.30: Greenhouse gases from cement manufacture



Note: Absolute emissions in this sector, estimated here for 2000, are 1,588 Mt CO_2.
Source: WRI

Improve or design new processes: Outdated production processes can be replaced with more efficient technologies, such as recovering heat from production or using catalysts to reduce the high temperatures needed during production. Certain industries, such as cement, plastics, and steel manufacturing would require a completely new production process for considerably reducing the industry's greenhouse gas emissions. For example, plastics are highly fossil fuel intensive. However, technology to produce plastics from biomass is emerging (for more examples, see section on chemicals on page 63).

Replace products: One could produce a replacement product to fulfill a certain lifestyle need, such as replacing newspapers with electronic news, or chemicals with enzymes.

Reduce material use: Through better design, many products can fulfill the same functions with much less use of materials. Examples include lightweight vehicles and packaging (see box on lightweighting on page 51). According to Novatlantis, manufacturers have reduced the weight of glass bottles 45% during the past 40 years, and project another 30% reduction through the use of ultra-light polyethylene coated bottles. In the case of consumer goods, improvements in materials use often go hand in hand with improved comfort (for example, smaller and lighter mobile phones).

Re-use and recycle materials: Recycling and reuse of energy-intensive waste materials and used products improves energy and resource efficiency.

More intense product use: Leasing, sharing, and renting lowers the demand for materials by lowering the non-used capital stock, which includes more efficient use of residential and office buildings. Information technology supports such a transformation; however, this is mainly a matter of organizational and behavioral adaptations.

Cement

Emissions reductions not so concrete

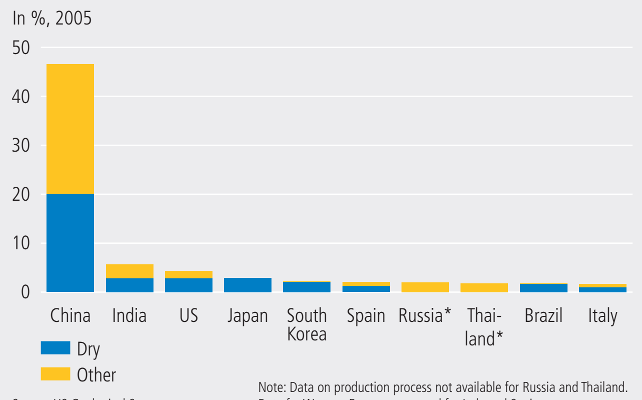
The cement industry accounts for approximately 5% of energy-related carbon dioxide emissions and 18% of greenhouse gas emissions related to industrial activities (see Fig. 4.30). Cement manufacturing emissions are the result of high energy demands to heat cement kilns, as well as the chemical reaction in making cement's main ingredient, clinker. The industry has made considerable progress during the past two decades in reducing the greenhouse gas intensity of cement production. However, cement demand is projected to grow another 140% to 160% through 2050, according to the World Business Council for Sustainable Development. Therefore, cement companies are faced with a considerable emissions challenge: in order just to compensate for growth, the cement industry would need to achieve a 60% reduction in specific emissions (that is, per unit of cement produced) by 2050 just to stabilize absolute emissions.

There are mainly three areas for reducing the emissions intensity of cement manufacturing: improving energy efficiency in the production process (for example, replacing the inefficient wet process with the dry or semi-dry process), changing the fuel mix (for example, using low-carbon fuels, such as natural gas, and increasing use of waste fuels, such as waste oil and old tires), and reducing the clinker/cement ratio (for example, replacing clinker with industrial byproducts, such as fly dust). According to a 2002 report from the World Business Council on Sustainable Development, measures in these three areas could improve cement-related emission intensity by at least 30%.

Whereas cement use in industrialized countries has stagnated, it is rapidly increasing in developing countries. China produced 47% of the world's cement in 2005, whereas the US accounted for 5% (see Fig. 4.31). Developing countries tend to use less energy efficient production processes, whereas developed countries have largely shifted to the more efficient "dry kiln" process. Considering that China produces less than half of its cement with the "dry kiln" process points to a high potential for lowering the emissions intensity of cement. Even though more energy efficient cement production technologies offer the potential to curb the industry's worldwide greenhouse gas emissions, this transition is already well underway in developed countries.

Like many other carbon dioxide-intensive industries, cement manufacturers could control emissions through a process of carbon dioxide capture and storage (see box on page 61). However, this technology is not a panacea for all companies within the industry. Ultimately, unless the cement industry

Fig. 4.31: Global cement production



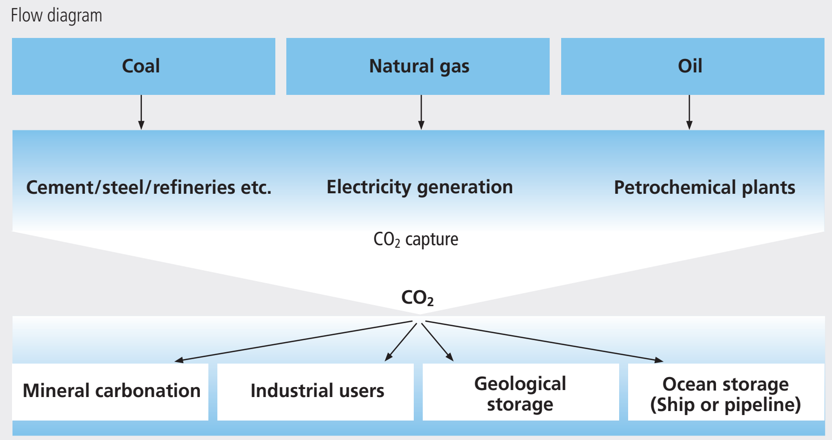
Source: US Geological Survey

Note: Data on production process not available for Russia and Thailand. Data for Western Europe were used for Italy and Spain.

Carbon sequestration

In an attempt to limit the amount of carbon dioxide that escapes into the environment from the burning of fossil fuels, industries and governments are investigating the potential for carbon dioxide capture and storage (CCS), either through underground and ocean storage, industrial use, and mineral carbonation (see Fig. 4.32). An IPCC report published in September 2005 concludes that capturing and storing carbon dioxide produced by power plants and factories could play a major role in mitigating the effects of climate change. Many components of carbon dioxide capture and storage technology are still in development, while others have already matured. For example, carbon dioxide has been injected into declining oil fields for more than 30 years to increase oil recovery. This option is economically viable because storage costs are offset by the sale of the additional oil that is recovered. However, this potential is not available for all CCS options. Somewhat ironically, power plants would have to generate additional energy to be able to sequester carbon dioxide, which would likely raise costs and electricity bills. Other possible applications, such as ocean storage or mineral carbonation are still in a research phase. Ultimately, unless governments adopt climate change policies that put a cost on carbon dioxide emissions, there will be little incentive to implement and develop this technology.

Fig. 4.32: Carbon dioxide capture and storage



Source: Intergovernmental Panel on Climate Change

reinvents the wheel and develops a far less energy-intensive manufacturing process, it is unlikely that it will reduce its overall greenhouse gas emissions. Even the most energy efficient cement production process involves large amounts of greenhouse gas emissions, which means that large emissions reductions are unlikely without a new product that can render cement obsolete.

Iron and steel

Minimal room for reductions

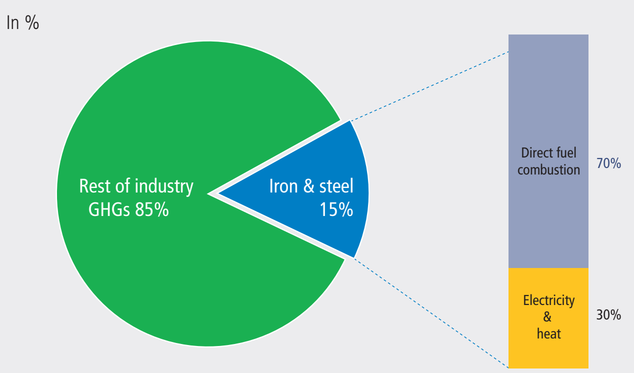
Iron and steel production generates a little over 3% of the world's greenhouse gas emissions and 15% of the emissions related to industrial activities (see Fig. 4.33).

There are essentially two methods for producing steel, which differ in energy and carbon intensity. The integrated process uses primary iron ore in a blast furnace and the electric arc furnace uses recycled scrap to make steel. According to a study by the International Iron and Steel Institute (IISI) the production of one metric ton of primary steel via the integrated process, which is used for about two-thirds of global steel production, emits 2.3 metric tons of carbon dioxide. Producing the same amount of steel via the electric arc furnace emits only between 0.12 and 0.83 metric tons of carbon dioxide, depending on the carbon intensity of the electricity used in production.

Steel demand is now growing at annual rates of between 3% and 5%, up from an average annual growth rate of 1% during the past 30 years, which is being fuelled by the same rapid infrastructure development and industrialization in developing countries that is having such a strong effect on cement demand growth (see Fig. 4.34).

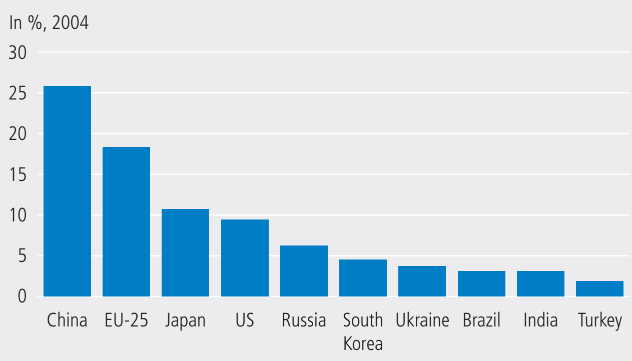
Curbing greenhouse gas emissions from steel production is achievable, but the likelihood of outright reductions is minimal. The further growth of lower-emissions production processes, such as the electric arc furnace, is limited mainly by the availability of scrap materials, but also by quality and durability constraints of recycled steel. In some applications, such as the automobile industry, steel is being replaced with alternative materials. Considered over the entire lifecycle, this substitution reduces greenhouse gas emissions in automotive applications. However, substitution effects can only hope to slow the growth in steel demand. According to the IISI, "improvements in [traditional] steel production efficiency are reaching theoretical limits, making direct reductions of carbon dioxide emissions nearly impossible" without initiatives to develop new breakthrough steel-making process technologies.

Fig. 4.33: Greenhouse gas emissions from iron and steel



Notes: Absolute emissions in this sector, estimated here for 2000, are 1,319 Mt CO_2.
Source: WRI

Fig. 4.34: Global steel production



Source: International Iron and Steel Institute

Chemicals (white biotechnology)

Microorganisms and enzymes to the rescue
The chemicals industry is highly energy intensive, relying on energy inputs for both fuel and raw materials and is therefore one of the biggest industrial emitters of greenhouse gases, accounting for 5% of the world total (see Fig. 4.35). Certain energy-intensive sub-sectors are more exposed, such as nitrogenous fertilizer production, ethylene production, and electrolysis. Yet while some chemicals offer limited room for emissions improvement, the overall mitigation potential for the industry is very high. The chemical industry can generate emissions reductions by developing more energy efficient production processes, and by engineering new products to improve the energy use and efficiency of a downstream process. One field that is at the forefront of these new technologies is biotechnology, which can yield large improvements in process substitution, as well as product substitution.

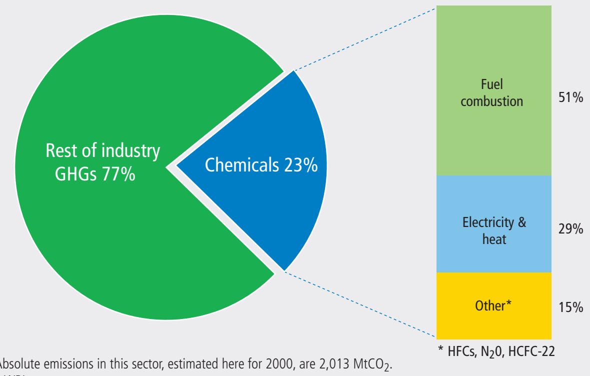
So-called "white biotechnology" uses microorganisms to produce chemicals that would previously have been produced in highly energy-intensive production processes. Such techniques have been applied for centuries in the food industry to brew beer (that is, yeast) and produce yogurt (that is, bacteria). Today's white biotech industry predominantly uses genetically modified microorganisms to produce specific chemicals, such as enzymes, hormones, vitamins, and antibiotics. The chemical products of white biotechnology range from very cheap bulk chemicals, such as ethanol, to extremely expensive fine chemicals, such as vitamin B12.

The aim of white biotech is to lower production costs and improve margins through reduced materials use and energy consumption. Although the reduction of greenhouse gas emissions is not a primary motivation, it is one positive outcome. For example, vitamin B2 (riboflavin), an important food and feed supplement, used to be produced in an expensive and complicated six to eight step chemical process. The new biological process, introduced in the 1990s, achieved a cost reduction of 40% to 50%. According to a BASF/Öko-Institut study, greenhouse gas emissions intensity was reduced 30% because of this process.

A good example of the product replacement potential through biotech products are enzymes, which are ideal for improving the eco-efficiency of industrial and downstream processes, by increasing yields and reducing energy and water intensity. Enzymes are proteins that act as catalysts to speed up chemical reactions that would otherwise occur at a much slower rate or not at all. Enzymes hold the potential for replacing many synthetic chemicals in industrial production and therefore for lowering the environmental impact of

Fig. 4.35: Greenhouse gas emissions from chemicals

In %



Note: Absolute emissions in this sector, estimated here for 2000, are 2,013 $MtCO_2$.
Source: WRI

many products. Enzymes are already being applied in areas such as biofuels, pulp and paper, food processing, animal feed, mining, and textiles, making these processes more efficient and more environmentally friendly (see Fig. 4.36). The largest single market for industrial enzymes (25–30%) is detergents. Enzymes allow clothes and dishes to be cleaned more effectively and at much lower temperatures, thus saving energy as well as water.

Increased use of white biotechnology in the chemicals industry holds significant potential for simultaneous cost reduction and energy savings. Many chemicals companies have started to review their product portfolios to identify the most suitable candidates for process substitution, as the cost savings would need to be large enough to pay back the initial investment costs. A McKinsey study from 2003 estimated the penetration of biotechnological production processes in the chemical industry at 5%, and expects it to increase to between 10% and 20% by the year 2010. The penetration speed will depend on a number of factors such as the prices for crude oil and agricultural raw materials, technological developments, and the political will to support and structure this new technology.

Regulation of industrial processes and materials use

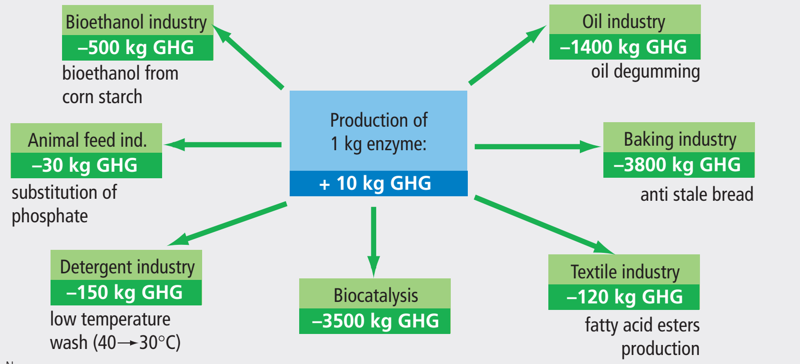
The industrial and materials sectors with the greatest potential for being included in new regulatory schemes are those with highly concentrated point source greenhouse gas emissions, such as the steel and cement industries. Along with other highly energy intensive industries, these are the ones that the EU Emissions Trading Scheme (EU ETS) now targets for emissions reductions.

The exposure to regulatory changes that energy-intensive manufacturing companies, such as steel and cement producers, will face depends on a company's technical ability, its geographic location, its product mix, and its management strategies. The direct impact of the EU ETS on industrial manufacturing companies during Phase I of the EU ETS was viewed as rather limited, as most companies were allocated a surplus number of permits. Indirectly, companies with high EU exposure had to absorb higher electricity prices caused by the introduction of the scheme. However, industrial processes located in Europe often have only little scope for further greenhouse gas emissions reductions and therefore might be forced to buy emissions credits during Phase II.

High volume industrial production is increasingly shifting to emerging market countries, where production is cheaper, closer to both the raw materials and the source of demand, and subject to less stringent environmental rules. Barring breakthrough production technologies, the only potential to

Fig. 4.36: Change in greenhouse gas emissions from enzymes

Potential reduction of greenhouse gas emissions (in kg) in separate industries from 1 kg of enzymes



Source: Novozymes

regulate these carbon emissions is within the context of a global emissions trading regime where the whole industry becomes net buyers of emissions rights. However, some industrial products, such as cement and steel, are an important part of today's constructed world, and there are many other areas where greenhouse gas emissions reductions can be achieved more efficiently. Cement is an important ingredient in economic development, which makes raising the cost counterproductive for achieving overall environmental goals in developing countries.

Apart from targeting point-source emissions, the other way to reduce the carbon impact of industrial processes and materials use is through regulating energy efficiency of products, mandating new technologies and products, and requiring phase-outs of certain products. Examples include energy efficiency standards for air conditioners and minimum performance standards for insulation materials.

Summary of industrial processes and materials use

For activities that involve industrial and materials production and use, the outlook for greenhouse gas emissions reductions is rather mixed. On the one hand, large industrial emitters have little potential to reduce greenhouse gas emissions. There is no substitute product or production process, and so demand growth will likely outstrip any efficiency gains or incremental process improvements, and the products form the foundation of most economic development. Energy-intensive activities, such as these, are easy targets for regulators. However, regulating emissions from these activities is potentially less cost-effective than for other activities. On the other hand, the chemicals industry and CCS technology could bring about significant reductions in carbon emissions, either directly or through indirect improvement in downstream processes.

Even though industrial processes and materials use will produce slower growth of greenhouse gas emissions than transportation, considerable emissions reductions as outlined by our 2,000 Watt scenario appear unlikely within the current regulatory framework. Energy intensive industrial processes may be easy targets for regulatory enforcement, but may involve costly measures to effectively reduce emissions and may not be practical in the context of the high infrastructure needs of developing countries. Often, the largest emissions reductions result from providing a product (or, in fact, a function) in a more energy-efficient fashion over the entire product lifecycle. Therefore, regulation of this sector would likely best be accomplished through standards that are based on best-available technology and that aim to define how products are delivered. However, such standards are difficult to enforce because it is often not clear where systems boundaries begin and end, and because final production involves many different products and many different producers.

It appears that there is very little direct implication for individuals from these activities because most of the end products have few substitutes and are often necessary for basic infrastructure. Nevertheless, it is ultimately the products and services that society demands that define the industrial processes needed to provide them.

Fig. 4.37: Summary table of industrial process and materials use activities

	Business as usual	Steps to achieve the 2,000 Watt scenario
Consumer behavior	Strong focus on amount and size of consumer products (status symbols).	Strong focus on quality rather than quantity of products.
		Strong focus on durability and functionality.
	Strong focus on products rather than services.	Less energy-intensive products make their way into the consumer mainstream, such as cold water detergents.
Technology	Standard production processes in high-impact industries (e.g., steel and cement) remain in place.	Breakthrough processes to reduce emissions of high-impact industries.
	Incremental energy efficiency improvements in industrial processes.	Introduction of disruptive technologies that change processes and products (e.g., biotechnology).
Regulation	Focus remains solely on large industrial point sources, rather than achieving reductions in other activities.	Policymakers expand their focus to include more cost-effective emissions sources.
	Clean Development Mechanism encourages companies in developed countries to invest in clean technologies in developing countries.	Stringent regulatory requirements on end-use energy efficiency of products.

Source: UBS

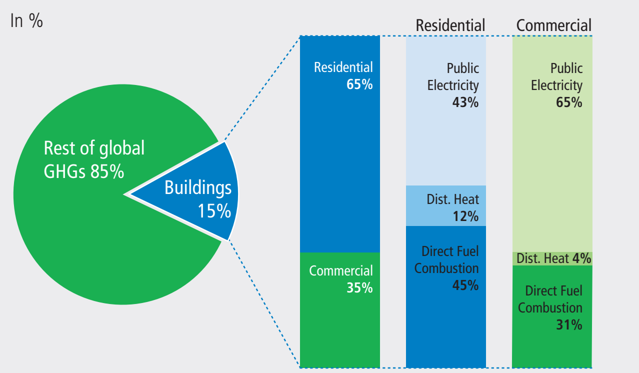
Building

Building activities are responsible for 15% of global greenhouse gas emissions (see Fig. 4.38) According to the European Commission, construction and maintenance of buildings, which includes such activities as heating, cooling, lighting, and use of electronic equipment, accounts for 40% of the energy use in the EU. The situation in the US is similar. Because of the long life of most buildings, today's construction decisions will influence a large share of the world's energy use and energy efficiency for several decades. Although an increasing number of new structures are built according to high energy-efficiency standards, the energy demand of buildings during the next several decades will be dominated by existing architecture. Therefore, new buildings and building improvements will need to be constructed according to the highest standards in energy efficiency in order to achieve meaningful reductions in greenhouse gas emissions.

Despite the slow turnover, buildings offer the largest potential for energy efficiency and reductions in greenhouse gas emissions. The average energy use of residential buildings is roughly 1,400 Watt per person. By contrast, the Swiss Minergie-P standard, which makes strong use of passive solar energy and establishes the highest energy efficiency standards for housing and commercial buildings, consumes just 350–550 Watt per person. This corresponds to a three- to four-fold energy reduction potential, which can be achieved without losing any convenience or comfort. Buildings based on standards, such as the Swiss Minergie-P or the German Passive House standards, are often referred to as "three liter houses", as they only require heating energy corresponding to three liters of heating oil per square meter of heated floor space per year. All of these building standards obtain the bulk of their energy savings through improvements in space heating and hot water supply (see Fig. 4.39).

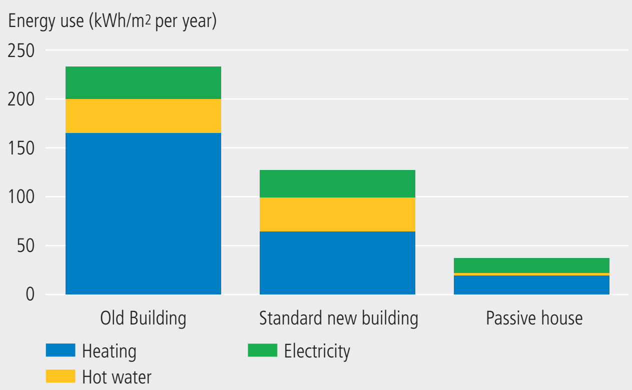
Most energy-saving options in buildings require large initial investments, which are later repaid through reduced long-run energy costs. This explains why most commercial enterprises take steps to implement best practices in energy consumption: companies usually can afford the more expensive upfront costs, can reduce operating expenses, and can publicly express their commitment to reduce greenhouse gas emissions. Although many residential energy consumers are not able to afford the high initial costs for efficiency enhancements, or are faced with a tradeoff between residential efficiency upgrades and other competing expenses, loans for efficiency upgrades could be repaid with lower long-term energy bills. The following are some options for controlling energy use and greenhouse gas emissions in building activities.

Fig. 4.38: Greenhouse gas emissions from buildings



Note: Absolute emissions in this sector, estimated here for 2000, are 6,418 $MtCO_2$.
Source: WRI

Fig. 4.39: Comparison of energy use of homes



Source: Energy Conservation in Buildings and Community Systems

Insulation: Building insulation works to protect against cold and heat, and is therefore necessary in cold and warm climates alike (see Fig. 4.40). Air conditioning demand is expected to double in Europe by 2020, and will accelerate in developing countries. More R&D needs to go into the development of high performance thermal insulation, which is less space consuming than conventional materials. This could greatly increase incentives to refurbish old buildings. In order to make refurbishments cost-effective, new insulation often needs to be combined with general building upgrades.

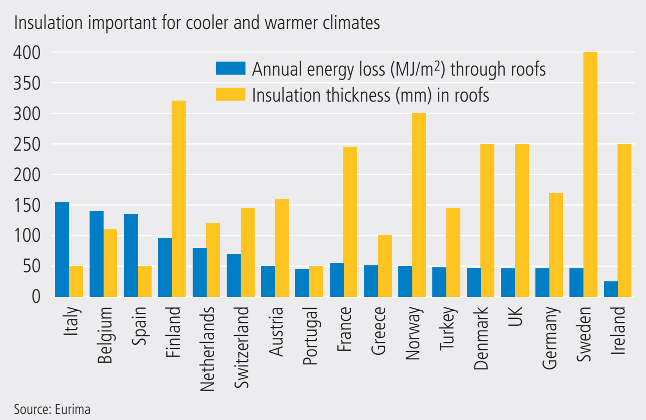
Passive heat: In colder climates, there is a large energy savings potential from combining proper insulation with increased solar exposure through optimal placement of blinds, shades, and windows (that is, passive heating). This greatly reduces the need for heating and cooling energy, which accounts for about half of the energy consumption in residential and commercial buildings.

Heating, cooling and ventilation: Heating and cooling systems are based on inefficient technology and not optimized to the actual comfort and space requirements. Ventilation systems, which are a key element of maintaining air quality and efficient heat recovery, are often deficient. One part of the solution is to replace or upgrade existing systems. For example, 10 million boilers in European homes are more than 20 years old, and replacement would save 5% of energy used for heating. The other part of the solution involves adjusting systems to the needs of the user. For example, intelligent software for energy management can play an important role in ensuring that energy is only used when needed.

Lighting: Lighting comprises between 5–10% of a residential building's energy consumption, and can account for up to 30% in commercial buildings. Customers can reduce their electricity consumption by up to 50% simply by upgrading the efficiency of their lighting, as demonstrated by several projects carried out under the guidance of the voluntary European Green-Light Program. Energy-saving technologies include compact fluorescent light bulbs, light emitting diodes, and fiber optics.

Electrical appliances and equipment: Electricity used in standby mode can make up between 5% and 10% of total electricity consumption in the residential sector, according to the IEA. Equipment with built-in power management features can greatly reduce energy use by switching to low-power mode when not in use. Like lighting, improving the energy efficiency of appliances can be implemented much faster than in areas that involve construction.

Fig. 4.40: Avg. European insulation thickness and heat loss



Renewable energy: In order to reduce the greenhouse gas emissions burden of the maintenance of buildings, renewable energy technologies, such as thermal collectors for hot water production and photovoltaic panels for electricity, also play an important role. Keep in mind, however, that the installation of such technologies can play a more significant role when other energy efficiency measures have been taken beforehand to reduce the overall energy need of a building.

Commercial and residential real estate

Although rental fees are perhaps the most important consideration for individual and corporate tenants, energy costs are also important. A real-estate property with high average annual energy costs will likely receive less demand from tenants than a similar property with low annual energy costs. Energy considerations are less important when energy costs are low, but are rather significant when energy costs are high. Buildings with higher energy efficiency can reduce their tenants operating costs and their exposure to wide fluctuations in energy prices. Therefore, energy efficiency improvements will technically improve a building's value through higher tenancy and occupancy rates.

Buildings in developed countries account for roughly 40% of total energy consumption. Therefore, it would appear on the surface that energy efficiency would be a high priority for real estate companies. However, the incentive for energy efficiency upgrades depends on whether the tenant or the property management company pays for energy use. This differs from country to country, and even inter-regionally within countries.

Companies with large real estate portfolios, such as hotel chains, senior care facilities, shopping malls, and supermarkets, typically bear the cost of energy consumption and therefore have a financial incentive to invest in infrastructure projects to reduce energy consumption. By comparison, office and residential properties typically offload the burden of energy costs onto the tenant. In these instances, since there is no ownership involved and little equity stake in the building infrastructure, tenants rarely have an incentive to make infrastructure upgrades.

Property owners have an incentive and the resources to improve energy efficiency through better managed infrastructure. This would then flow down through the value chain: better managed properties would theoretically have higher occupancy rates and therefore higher value. Furthermore, as more and more buildings are "graded" according to their energy efficiency, this may cause inefficient buildings to command less value in the real estate market.

Long-term leases can also act as barriers to efficiency improvements in buildings. By design, tenancy is often slow to change. Long lease contracts further discourage property owners from undertaking cost reduction measures on behalf of their tenants.

Real estate investment trusts

Historically, people could only benefit financially when they made energy efficiency improvements to their own property. However, access to liquid forms of investment in real estate has increased significantly with the proliferation of real estate investment trusts (REITs). REITs are similar to publicly-quoted real estate funds, although some technical and tax classifications exist. The REIT structure was designed to provide a similar structure for investment in real estate as mutual funds provide for investment in stocks.

REITs will primarily benefit from improvements in energy efficiency across their portfolios through reductions in operational costs. These improvements in turn will positively impact net operating income, which in the case of REITs may have potentially beneficial impacts on valuation, mainly due to the fact that REITs are required to return the majority of the operating income back to shareholders.

Building regulation

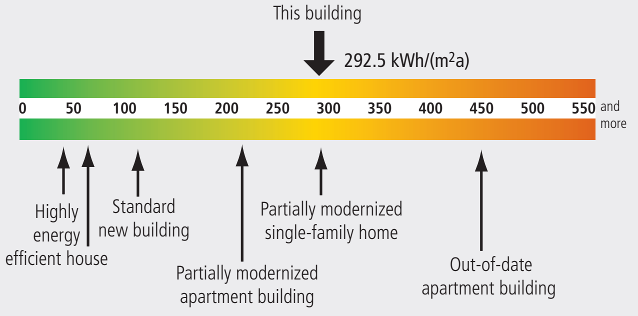
No country imposes energy performance standards equivalent to a passive house standard, and only a small percentage of homes and buildings are constructed according to these strict guidelines. Margin pressure in construction is high, and price is the overwhelming criteria for project approval. Without explicit requests, stricter energy efficiency standards are unlikely to be voluntarily implemented, in spite of the fact that higher initial investments are often paid back within a few years due to lower energy costs.

Countries are sporadically implementing new standards and incentives to improve energy efficiency in buildings. In the US, the 2005 Energy Policy Act contains several incentives, such as tax credits for residential photovoltaic systems or for improvements to existing homes, including high-efficiency air conditioners and equipment. The most revolutionary European regulation is the Energy Performance of Buildings Directive, which has been implemented by all EU countries plus Norway and Switzerland as of January 2006. Some of the requirements contained in the directive are that energy codes must be updated at least every five years and that buildings undergoing major modernization must be brought up to the new energy efficiency standards.

The directive also implemented an energy certificate program for all buildings that are constructed, rented, sold, or have public access (see Fig. 4.41). This is a user-friendly tool to give tenants, landlords, owners, and potential purchasers the necessary information to evaluate the constructive and energetic condition of a building, expected costs, and the potential need to renovate or modernize the building.

Fig. 4.41: "Energy Pass" label

In kilowatt hours per square meter per year



Source: Deutsche Energie Agentur (dena)

Summary of buildings

People in developed countries can achieve virtually the same living and working conditions as they do now, but with far less energy consumption. Buildings based on best-available practices consume less than one third of the energy of an average building, and with technology that is already available. However, residential and commercial buildings are constructed in ways that are highly energy inefficient and take little advantage of renewable energy sources, such as solar and geothermal power. Moreover, the location of homes in many countries is in poor proximity to public transport or essential services, which necessitates energy consumption via inefficient forms of private transportation, such as longer commuting times and more road traffic for shopping and entertainment.

The potential for energy efficiency in buildings is very high. Policies that make building energy consumption more transparent, such as the "Energy Pass" label, will help to establish energy efficiency as a mainstream market force. Nevertheless, due to the long life of buildings, changes cannot be implemented quickly. Today's construction decisions will influence building energy use for several decades. Hence, in order to get on the trajectory as outlined in our 2,000 Watt scenario, requires more stringent regulation to ensure that new buildings and building improvements adhere to the highest standards in energy efficiency. Although these standards might increase the cost of construction, the energy savings would eventually reimburse the higher initial upfront costs. City and residential planning that considers inter-modality is critical to reducing the indirect effects of buildings on energy use. Tenancy agreements that create incentives for property owners to invest in energy efficiency improvements are superior to those that channel energy expenses to tenants.

Fig. 4.42: Summary table of building activities

	Business as usual	Steps to achieve the 2,000 Watt scenario
Consumer behavior	Initial building costs continue to dominate building decisions, with little consideration of operational costs.	Demand for eco-efficient passive homes increases.
	Increasing space demands.	Office properties continue to seek energy efficiency gains, as energy costs become integrated into investment decisions.
	Large centralized power plant development. Limited attention to urban and regional planning and the impact of commuting.	Energy efficiency labels form part of real estate asset valuation and an important criterion in property purchasing.
Technology	The technology is available. The question involves the speed at which it is applied. Slow ← → Fast	
Regulation	Codes continue to leave a majority of building efficiency decisions to free market outcomes.	Building standards mandating higher energy efficiency in homes and offices.
	Limited expansion of subsidies and tax rebates to encourage energy efficiency.	
	Introduction of energy pass label for raising information on energy efficiency in buildings.	

Source: UBS

Summary of chapter 4

A large gap exists between projected greenhouse gas emissions and the direction they would need to head in order to stabilize atmospheric greenhouse gas concentrations and avoid the more severe outcomes of climate change forecasts. As we have shown in the preceding analysis, technological solutions to lower emissions are available, particularly within the activities of energy delivery, building, and transportation. The sector that can have the most immediate effect is transportation because of the relatively fast turnover rate of automobiles and the emerging availability of high-efficiency models. Among the building and energy delivery activities, changes would need to occur rapidly in order to alter the emissions trajectory because infrastructure is built with long life spans. Once again, the technology to do so is also available. Meanwhile, certain energy-intensive industrial activities will not allow for significant emissions reductions without breakthrough, and as yet unavailable, technologies to create substitute products or processes. Oddly, these are precisely the activities that emissions trading regimes are targeting to achieve emissions reductions. Meanwhile, global policies to reduce emissions where the ability is highest are virtually non-existent. Yet these policies are necessary to create incentives and to alter behavior.

Therefore, a higher emissions path appears likely for the foreseeable future. Specifically, we expect the following:
- increased demand for private modes of transportation and other energy-using consumer products, but slow growth in the most fuel-efficient options;
- a slower rate of adoption and implementation of available energy-efficiency technologies than is necessary to stabilize and reduce emissions, such as in building and energy delivery;
- limited emission reduction opportunities in primary materials production, such as cement and steel; and
- limited infrastructure enhancements to alter behavioral patterns, such as greater availability of inter-modal transport and decentralized energy delivery architecture.

The principal reason for this opinion involves the insufficient policy framework for creating incentives to reduce emissions from numerous, small point sources. While there are undoubtedly individuals who are taking steps to lower their own contribution to greenhouse gas emissions, large-scale emissions reductions require long-term, tractable policies and incentives. There are many available policy options for reducing emissions, as we outline in the appendix, and it is still too early to judge the potential for success or failure of future policy decisions. After all, global awareness of climate change is relatively young, and most of the policy initiatives that have been brought into force are still in a "test" phase. Meanwhile, international political momentum is growing for emissions containment, and public support for emissions policies is on the rise. There is still time to develop an effective policy regime to reverse the projected higher emissions path. However, time is running short. The longer it takes for policies to be implemented, the harder it will be to contain emissions concentrations and reduce the risks of more severe climate change events.

The nexus of financial services and climate change

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How does the financial services industry play a role in reducing greenhouse gas emissions?
Financial services is a very broad industry, encompassing asset management, insurance, reinsurance, banks, rating agencies, hedge funds and institutional investors, to name just a few. I think all of these are relevant when discussing climate change, but each segment has a different role to play. Generic roles that financial services companies play fall into four key areas: asset pricing, corporate finance, risk management, and security ownership.

Given these roles, there are many ways in which financial services companies can influence greenhouse gas emissions. For example, credit rating agencies incorporate risks from greenhouse gas emissions into their overall risk quantification, which are then translated into changes in a company's cost of capital. Insurance and reinsurance companies have to cover costs of damages from extreme weather events. Therefore, a key component of their business is to raise awareness of climate change issues among the public, their customers, and policy makers. Asset managers incorporate greenhouse gas emissions into their investment appraisal, criteria and decision making.

Everyone who invests money would want to ensure that they receive an appropriate risk-adjusted return, after incorporating risks from greenhouse gas emissions into their investment decisions. The same applies to the opportunity side. When taking a mid- to long-term investment approach, investors will want to screen for new technologies that can help to reduce greenhouse gas emissions and particular sectors with investment opportunities related to reducing emissions and lower dependence on fossil fuels. The financial services sector has an incentive to reflect risks of climate change in their daily practices, even without regulation. The assumption is that climate change is happening and has an impact. If there are restrictions on greenhouse gases in the future, then this is even more the case because it impacts virtually all industry sectors and investments.

What market-based programs are in place for routing investment capital according to climate change criteria?
From my perspective, there are no pure market-based programs that are specifically intended to route investment capital according to climate change criteria. However, there are quasi-market-based programs that are designed to associate either a cost or a price with greenhouse gas emissions, which would indirectly influence how a company allocates investment capital. For example, the European Trading Scheme was designed to develop a market price for CO_2 emissions. Although the ETS is still in its infancy, the trading framework is beginning to build in a cost for CO_2 emissions.

Other market mechanisms that are considered within the Kyoto Protocol include the Clean Development Mechanism and Joint Implementation frameworks. These programs are intended to provide incentives to invest in projects that will reduce CO_2 emissions. One could argue that these programs are intended to channel investment capital with the goal of reducing emissions. For example, a company could decide to invest in a solar power project in India. The investing company would then have the revenue from the project itself and in addition could sell the carbon rights gained from the project. This provides an incentive that might not have occurred otherwise.

What are some of the important developments taking place within the financial services industry that are specifically aimed at addressing climate change?
To reach a point where climate change is incorporated and implemented into financial services, industry practices would first require a more thorough understanding and awareness of the issue, followed by improved data gathering and a workable methodology for assessing climate change. With this foundation and shared awareness, the industry is better equipped to change behavior and industry practices to respond to risks associated with climate change.

The first big development, and clearly a first-step in this process, is the Carbon Disclosure Project, which allows for greater transparency, disclosure, and data availability on emissions. This project began as a voluntary initiative and now involves 200 financial companies globally, with USD 31 trillion in investment capital. The Enhanced Analytics Initiative represents another development that has implications for climate change. EAI members, primarily institutional investors and asset managers, agree to set aside 5% of their brokerage commissions to fund extra-financial research activities, such as sustainability. Although not specifically a climate change initiative, the subject is part of the larger topic of sustainability. These are first steps, but more work needs to be done to develop industry "best practices" and quantify how to bring greenhouse gas emissions into a fully-fledged methodology for the financial services industry to address climate change.

How can individual investors play a role in influencing climate change, particularly as it pertains to their own personal investment portfolio?
Currently there is something of a stalemate between companies and governments regarding climate change. Governments say that companies need to reform their prac-

tices on their own and that radical regulation will harm the economy, while companies argue that politicians need to provide a framework to reduce uncertainty and make sustainable long-term investments. Investors could break the impasse by raising the issue and demanding solutions. The issue with climate change is that it is so global and so huge that individual investors may not think they can do anything about it. Hopefully, people understand that they can have an impact, that their investment decisions do matter, and that the time to act is now.

How does climate change risk affect investment risk?
When one discusses climate change risks, one can subsume them all under the heading of "carbon risk" and from there you have a multitude of possible risks. These risks range from physical damages to assets, future regulations to address greenhouse gas emissions, market price risk in some sectors from CO_2 emission trading schemes, fuel price risks, litigation risks, and reputation and operational risks. All investors need to understand the risk that climate change will have on their portfolio and come up with scenarios about how certain risks will develop. Ideally, investors could identify the value of their portfolio that is at risk from climate change and how much risk they are willing to tolerate.

However, to do this, greenhouse gas criteria need to be defined and quantified so that they are evaluated along with other investment criteria that one considers in making an investment decision. Take a look at utilities, for example. This is an asset-intensive industry, and companies within the industry make long-term investments in assets. Investors should understand how regulation of the utility industry will impact their portfolio if people start to take climate change seriously. Companies building CO_2-intensive power plants today run the risk that future government policies will render the power plant a stranded investment at some stage. Short-term investors may not take an interest in these issues, but long-term investors, such as pension funds and insurance companies, will need to understand the impact this has on their investments.

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Chapter 5

The investment risks and opportunities of climate change

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With contributions by:
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The investment risks and opportunities of climate change

A changing climate will produce serious ramifications for the world's business and investment climate. We provide a blueprint for thinking about the risks and opportunities.

The risks and opportunities of climate change

Investment strategies based on climate change criteria may not necessarily produce higher expected future returns, compared with strategies that are based on other factors. Aside from this, investment strategies of all types will need to consider the impact of policies and forces related to climate change and their effect on the future business and regulatory environment. This will increase the risk profile for some sectors and companies, while providing significant growth opportunities for others.

An increasing number of companies and financial market participants are incorporating climate change criteria into their business plans and strategies. In some instances corporations are adjusting their behavior in advance of expected policy changes and regulation. In other instances, investors are discovering ways to account for the implications of climate change within their investment process. This involves directing capital to, and promoting the development of, those businesses that contribute to mitigating climate change, while spurning investments in companies that are the most culpable.

In order to survey the investment implications of climate change, we identify three key criteria for evaluating the risk and return prospects:

- First and foremost is the policy response. That politics and energy are closely linked should come as no surprise; the relationship is a function of important strategic and business interests. Greenhouse gas emissions are simply the latest wrinkle in an already complicated political landscape surrounding energy policy. The policy mandate extends beyond energy use and production, to include environmental concerns.
- Secondly, industry exposure to greenhouse gas emissions and the potential for voluntary reform will likely determine the extent to which these sectors are subjected to regulation. Those industries that are unable to adapt may find that strong domestic and international political forces will dictate outcomes.
- Thirdly, the corporate response to climate change and greenhouse gas emissions will determine company-specific exposure to risks and opportunities.

With this framework in mind, we will merge the policy discussion outlined in the appendix with the industry assessment in chapter 4, to discuss how investors can structure their investments so that they can incorporate the potential policy response to climate change, the physical and business risk of a changing climate, and the opportunities to mitigate climate change.

Policy and regulatory environment

The most important driver for mitigating climate change, and consequently the most important driver for the resulting investment risks and opportunities, is the future regulatory framework. There are three reasons for this:

- **Increasing greenhouse gas concentrations are the result of market failures.** Generally speaking, greenhouse gas emissions do not yet incur a cost. The European Union Emissions Trading Scheme (EU ETS) represents the first wide-scale attempt to assign prices to carbon dioxide emissions. As explained in chapter 3, external environmental costs must be internalized via regulatory change to become a material driver of corporate decisions.

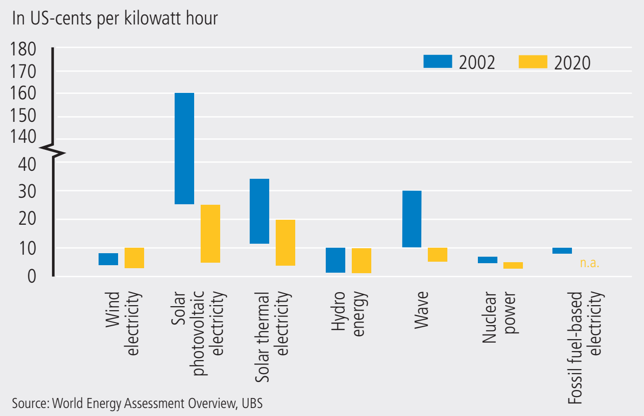
- **Few cost-competitive alternatives to fossil fuels.** Many renewable energies and energy-efficient technologies and services, which may contribute to climate change mitigation, are not yet cost-competitive when compared to energy from oil, natural gas, and coal. Fig. 5.1 shows the current costs of producing electricity from different sources and projections for 2020. If external costs, such as the costs of environmental degradation and future damage from climate change, were included in the price of fossil fuels, renewable energy sources would become more cost-competitive. Political support (for example, subsidies and tax breaks) improves the cost-competitiveness of new energy technologies, by raising demand, reducing costs through economies of scale, and promoting further technological advances. Even in an environment of liberalized energy politics, a country's current and future energy mix is still partly a political decision.
- **High national strategic importance of energy.** A secure and abundant supply of energy is a widely shared national priority. Encouraging the use of domestic energy supplies and alternative energy sources to reduce dependency on foreign energy sources usually manifests itself in the policy realm.

Policies to rein in greenhouse gas emissions could have a dramatic affect on long-term revenues and costs, both negatively impacting companies with high carbon exposure, as well as providing above-average growth opportunities to companies that offer solutions to mitigate climate change.

In the case of renewable energy, political support often influences market outcomes. In Germany, the adapted Renewable Energy Sources Act, which came into force in 2004, included subsidies for solar installations. This development sparked an increase in newly installed photovoltaic capacity (the production of electricity from sunlight), as well as boosted the share price of solar stocks (see Fig. 5.2). In the case of the US ethanol market, production grew from 660 million liters in 1980 to roughly 15 billion liters in 2005, with support from federal and state ethanol tax subsidies and other national policies (see Fig. 5.3). Consequently, capital flows to the US ethanol market have increased markedly: during 2006, several pure-play US ethanol companies raised equity capital through initial public offerings and private placements.

China's 11th Five-Year Guidelines, which span the period from 2006 to 2010, target an aggressive increase of alternative energy production, with a focus on wind, biomass, and waste incineration, and are supported by a new "Renewable Energy Law". The guidelines have the goal of increasing renew-

Fig. 5.1: Cost range for electricity generation



Source: World Energy Assessment Overview, UBS able energy capacity by up to 10% of total capacity by the year 2020. As China is a large emitter of greenhouse gases with the potential for significantly increasing energy consumption, these policy developments may serve as an example for other developing countries. As with political support of renewables in developed countries, government initiatives in developing countries will also likely produce burgeoning industries and investment opportunities.

Energy politics are part of a country's broader national strategic interest. Not only will regional variations in climate favor different renewable energy technologies, the focus of R&D to mitigate climate change, as well as technical and business knowledge, will differ from country to country. Therefore, policies will take on a local flavor, even if they are part of a larger multinational framework. This is already true of the Kyoto Protocol, which allows individual countries to determine the best strategies to reduce greenhouse gas emissions.

Industry exposure

In assessing the sectors that are potentially most affected by climate change, one needs to distinguish between direct and indirect greenhouse gas exposure, and identify industries that have physical, or operational, exposure to climate change.

Direct exposure

The industries and sectors with direct carbon exposure are those that produce large greenhouse gas emissions as a result of their processes. Fig. 5.4 shows the share of global greenhouse gas emissions by sector. The figure illustrates that companies in the utilities sector and in certain industrial sectors (for example, chemicals, cement, and steel) have the largest direct carbon dioxide emissions and thus potentially the largest direct carbon liabilities. Consequently, the first phase of the European Union Emissions Trading Scheme (EU ETS) covered the electricity sector, as well as industrial installations that manufacture iron & steel, cement, glass, lime, brick, ceramics, and pulp & paper. As we point out in the appendix, other regulations, such as emission caps and technical standards, attempt to directly control greenhouse gas emissions from point sources, although they may not be the most cost-effective options. To limit the cost impact of regulations, industries that emit greenhouse gases can invest in low-carbon technology, trade emissions rights, invest in offset projects, and lobby to block or challenge regulation. Companies with low greenhouse gas exposure within a particular polluting industry are in a relatively strong position.

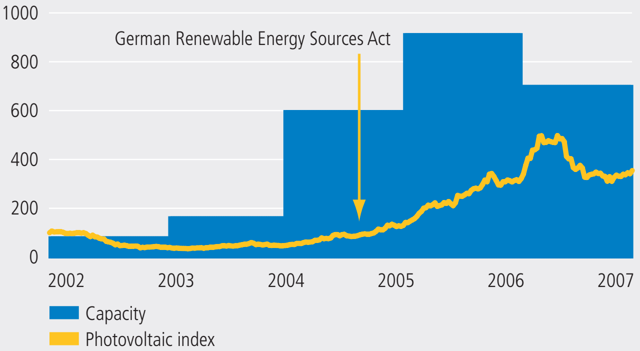
Fig. 5.4: Sector summary of greenhouse gas emissions
(in %)

Sector	Share of global greenhouse gas emissions
Electricity & Heat	24.6
Transport	13.5
Motor Vehicles	9.9
Aviation	1.6
Industry	21.1
Chemicals	4.8
Cement	3.8
Steel	3.2
Aluminum	0.8
Buildings	15.4
Agriculture	14.9
Land-use change & Forestry	18.2
Waste	3.6

Note: Sectors shown do not comprise 100% of global emissions, nor are all sectors mutually exclusive.
Source: WRI

Fig. 5.2: Photovoltaic capacity and share price index

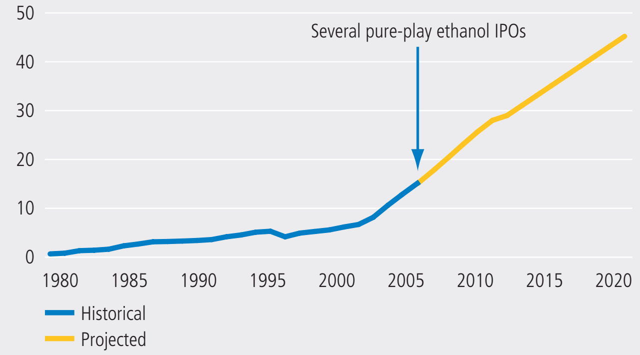
Newly installed capacity in Germany (in megawatt) and photovoltaic share price index



Source: Öko Invest Verlags GmbH, Solar Verlag GmbH, Photon, Bundesverband Solarwirtschaft

Fig. 5.3: Historical and projected ethanol use in the US

In billion liters



Source: F.O. Licht

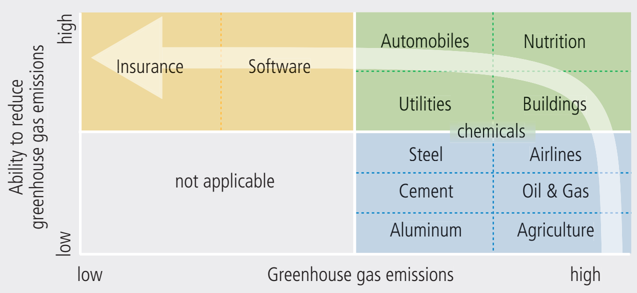
Indirect exposure
Companies that have an indirect exposure to carbon risk either manufacture products that emit greenhouse gases during their use, or offer services that are affected by greenhouse gas regulations. The most prominent example of indirect exposure is the automobile industry, whose products are responsible for almost 10% of global greenhouse gas emissions. Companies active in the construction of private houses and commercial buildings, or the manufacturing of electronic devices are also responsible for indirect greenhouse gas emissions when the final products are in use. The oil and gas sector is responsible for a large share of direct greenhouse gas emissions through mining, refining, and distribution operations, but is primarily an indirect emitter of greenhouse gases.

These sectors are exposed to carbon risk via changing consumer demand, which is motivated by a mix of internalization of macroeconomic costs of greenhouse gas emissions, rising prices of fossil fuel energy sources, and enhanced environmental awareness. In addition, companies manufacturing greenhouse-gas-intensive products may also be directly affected by greenhouse gas regulations. In the US, the Corporate Average Fuel Economy standard requires manufacturers to pay a penalty if the average fuel economy of its annual car or truck production falls below the defined standard. Another example is the European Union's 2005 Directive on the Eco-design of Energy-using Products (EuP), which encourages standards among EU member states for the development of energy-efficient EuPs.

Sectors with direct greenhouse gas emissions from large point sources bear the highest regulatory risks, as these sources are most easily monitored and controlled. However, most of the large industrial point sources have limited ability to adapt and are increasingly located in developing countries, which are not obligated under the Kyoto Protocol to reduce emissions. Furthermore, many of these activities are involved in primary economic production of goods that are at the very foundation of our economy and have no perfect substitutes, such as cement, steel and food. Therefore, effective climate change policies may also need to target the sectors with high indirect emissions and high ability to adapt. In these sectors, such as road transport, buildings and utilities, reductions in greenhouse gas emissions are the most cost-efficient from a macroeconomic point of view. The potential for adaptation in the different sectors is explained in detail in chapter 4 and illustrated graphically in Fig. 5.5.

Fig. 5.5: Greenhouse gas emissions and ability to reduce emissions

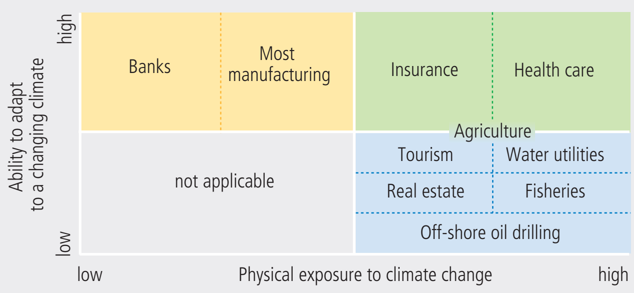
By sector or activity, arrow indicates the potential path to lower emissions



Source: UBS

Fig. 5.6: Physical exposure to climate change and ability to adapt

By sector or activity



Source: UBS

Physical exposure
Assessing the potential physical, or operational, exposure to climate change yields a different picture. Sectors whose operations depend on climate conditions have a high level of physical exposure, as do sectors whose operations would be interrupted by extreme weather events. Examples include agriculture, fisheries, forestry, water utilities, and water-intensive operations, but also tourism, healthcare, insurance, and operations sensitive to storms, such as offshore oil drilling. The ability to adapt to a changing climate also varies between sectors (see Fig. 5.6). For example, the insurance industry may adapt to changing weather conditions by modifying policy pricing, whereas a ski resort that does not have the capacity to receive or generate snow will have to drastically change its business model. Impacts of physical climate change will be felt for a long time. However, estimating the physical impact of climate change involves a high level of uncertainty.

Evidence of the severity of this increased risk is evident in insurance company issuance of catastrophe bonds to hedge against the risk of weather-related natural disasters (see discussion of catastrophe bonds on page 92). For example, insurance companies that underwrite real estate and other property in flood zones are issuing catastrophe bonds more frequently. This increased risk is also evident in the use of insurance and weather derivative products among ski resorts and oil & gas distributors.

Corporate exposure
In addition to differences between sectors, companies within a particular sector will have different abilities to respond to climate change regulations. Deriving direct buy and sell recommendations for a whole sector on the basis of carbon exposure is difficult; it is far easier to identify companies according to their relative exposure to climate change risks and mitigation opportunities, given wide differences in greenhouse gas emissions, potential for emission reductions, and competitive positioning towards tighter regulations.

How can one identify companies that will succeed and fail in an environment of heightened climate change risk? The following questions are helpful:
- Does the company operate in a regulatory environment where greenhouse gas emissions are regulated? If not, when and in what form is regulation expected?
- Has the company's top management acknowledged that climate change is a fact and a risk? Has management assessed the link between climate change and its business?
- How high are greenhouse gas emissions for a specific company, on an absolute level as well as relative to its peers? Does the company track indirect greenhouse gas emissions from the use of its products and its supply chain? Is there potential for emissions reductions? Has the company set reduction targets and a strategy for how to implement them?
- Are there business opportunities from climate change mitigation and increased regulation?

Finding answers to these questions is complex, but possible. The Carbon Disclosure Project (see box on carbon disclosure on page 85) is an important development for helping to answer these questions because it delivers information in an aggregated and comparable format. Corporate annual reports, environmental sustainability reports, and supporting documents also provide additional information, but are less transparent and lack a uniform reporting standard.

Risks related to climate change
Qualitatively speaking, companies scoring poorly compared to their peers (due to high emissions, high regulatory exposure, limited emissions reduction potential, and an inadequate corporate climate change strategy) have a

higher risk of being negatively affected by carbon regulations, which could lead to higher stock price volatility, lower returns, and, in extreme cases, credit default. As is generally the case over the long term, companies that survive are those that quickly adapt to changing circumstances, and that are open to innovative technologies and new business models. This is easier in theory than in practice. After more than one hundred years of existence, only one of the original twelve companies in the Dow Jones Industrial Average is still a part of that index today.

Quantitatively, carbon risks can be integrated in financial valuation models in a similar way as other risks. Carbon risks can be incorporated into a discounted cash-flow model (typically used to determine the value of an equity security by calculating the present value of future cash flows) in the following three ways:
- by adjusting the estimated terminal value,
- by changing the actual cash flow estimates, and
- by altering the discount rate with a higher/lower risk premium.

Changing cash flow estimates is suitable in situations with little or no uncertainty about the impact of climate change regulations on a company's revenue stream. In cases where the implication of forthcoming climate policies or the probability of future legislation is uncertain, it may be more appropriate to upwardly adjust the discount rate, which is the required rate of return, to reflect the carbon risk to which a company is exposed.

Where companies are subject to a government-sponsored cap and trade scheme for greenhouse gas emissions, the overall emissions and emissions rights may eventually need to be reflected in a company's financial statements. Although not a reporting requirement, the International Financial Reporting Interpretations Committee is working to develop guidelines for recognizing emissions allowances on the balance sheet and for valuing them as an intangible asset. Some companies affected by the EU ETS are already beginning to reflect the value of emissions rights, either shortfalls or surpluses, in their financial statements.

Opportunities related to climate change mitigation

The opportunities related to climate change mitigation are generally clustered into two categories: improving energy efficiency and increasing the use of low- and no-carbon fuels (see Fig. 5.7). Along with further regulation of greenhouse gas emissions and political support for technologies and services to mitigate climate change, above-average growth opportunities will likely emerge for several companies.

Considering the low level of market penetration of many of these technologies today compared to the potential growth, opportunities may well persist for an extended period of time. In general, as is the case with most technological innovations, alternative energy and energy efficiency technologies are either developed by large companies with enough R&D spending power to support a wide range of possible breakthrough technologies, or by small companies whose commercial success depends exclusively on the success of their innovation. These small companies often represent pure-play investment opportunities in climate change mitigation. Apart from the usual due diligence that is done before investing in small-cap companies, we list important issues to consider before choosing an investment in this area:
- Political support is currently the most important driver of outcomes, including the potential for new opportunities to address climate change mitigation.
- Technologies that reduce greenhouse gas emissions over the whole lifecycle of a fuel source or product stand to benefit from policies that aim to mitigate the effects of climate change. In this respect, energy sources with

the least greenhouse gas emissions are preferable. The carbon balance of producing renewable energy plays a role in determining the technologies that governments will support.
- Energy technologies that reduce greenhouse gas emissions are in different stages of the technology "lifecycle" (see box on renewable energy market penetration on page 84). Accordingly, the risk-return profile of investments in these technologies differs considerably. In general, the risk and expected return of renewable energy investments is greatest for companies pursuing new technologies that are not yet profitable. Risk and return begins to decline for companies that rely on existing government subsidies to generate profits. The lowest risk is associated with companies that offer a profitable product mix without the need of subsidies. Fig. 5.8 lists currently available technologies in this scheme.
- Cost-competitiveness and the potential for cost reductions are other important considerations when looking for opportunities. Fig. 5.1 shows the current cost of producing electricity from different sources and projec-

Fig. 5.7: Summary of opportunities related to climate change mitigation

Energy efficiency

Building	Investment area
Thermal insulation: the entire European Kyoto Commitment could be achieved with improved insulation; large potential exists in old buildings; more stringent building legislation and increasing energy prices will drive further investment in this area (see page 68).	Producers of insulation materials, high performance windows, and window frames.
Lighting: a conventional light bulb wastes more than 90% of its energy as heat; light emitting diodes produce virtually no heat (see page 68).	Producers of light emitting diodes (LED), fiber optics, and compact fluorescent light bulbs.
Heating, cooling, and ventilation: large potential for integrated systems that are adjusted to needs in new buildings; systems would also have applications in older buildings (see page 68).	Integrated systems for heating, cooling and ventilation; facility management with focus on energy efficiency; energy contracting; metering devices; IT solutions for intelligent energy management.
Household and electronic goods: electronic appliances constitute an increasingly large share of household electricity use (see page 68).	Energy efficient appliances, such as washing machines, dishwashers, refrigerators, freezers, air conditioners, and other electronic appliances with built-in power management systems.
Transport	**Investment area**
Lightweighting: there is a strong positive correlation between weight and energy use; lightweighting makes sense from a resource/energy use perspective, as well as from an economic point of view; applications are crucial for transportation, but also energy generation (for example, wind) and consumer products (see page 51).	Carbon fiber, composite materials (carbon fiber, glass fiber), lightweight solutions for aluminum, magnesium, titanium, plastics.
Drive trains: large efficiency improvement potential exists in conventional engines, as well as in alternative drive train technologies, such as hybrids and fuel cells (see page 55).	Automotive suppliers with innovative technologies, leading car manufacturers, fuel cells.
Technology and electronics: systems that help to make traffic flow more efficient (for example, for avoiding traffic jams on roads, and waiting loops in air travel) are an important element of more sustainable transportation concepts (see page 50).	Global positioning systems; highway traffic management systems; providers of real-time traffic information.
Electricity production	**Investment area**
Combined heat and power: combined heat and power doubles energy efficiency, as it makes use of both electricity and heat. This makes the technology very cost competitive. The trend to more liberalization of electricity markets will support further penetration of this technology (see page 42).	Independent power producers.
Industrial processes and materials use	**Investment area**
White biotechnology: industrial biotechnology can contribute to making industrial processes more efficient by developing new products with reduced environmental impact and energy use, and by offering products that reduce their customers' energy use (see page 63).	Pure-play industrial biotechnology companies, especially enzyme producing companies (one high potential area: enzymes for producing second-generation biofuels).

Renewable and low-carbon energies

Sector	Investment area
Wind: at certain sites, wind energy is cost-competitive with electricity from fossil fuels; capacity has grown from 2.8 GW in 1993 to 59 GW in 2005 (CAGR of 30%); annual growth of at least 20% during the next five years is likely (see page 46).	Turbine manufacturers, wind park developers.
Photovoltaic: if cost cutting continues in the next decade as in the last, photovoltaics will become cost competitive in the next 10–20 years with retail electricity prices (see page 46).	Entire supply chain (i.e., from silicon production and equipment suppliers to cell production and installation of photovoltaic modules).
Geothermal: price competitive at certain sites today; big advantage that it provides base load electricity (see page 46).	Geothermal project developers.
Biofuel: currently experiencing widespread political support due to the demand for energy independence (see page 52).	Biodiesel and bioethanol producers.
Solar thermal power: large growth opportunity in the world's sunbelts and carries large cost reduction potential (see page 46).	Solar thermal project developers.
Hydropower: limited expansion potential in Europe, but in other parts of the world small hydro project are a reasonable part of the energy mix (see page 46).	Small turbine manufacturers.

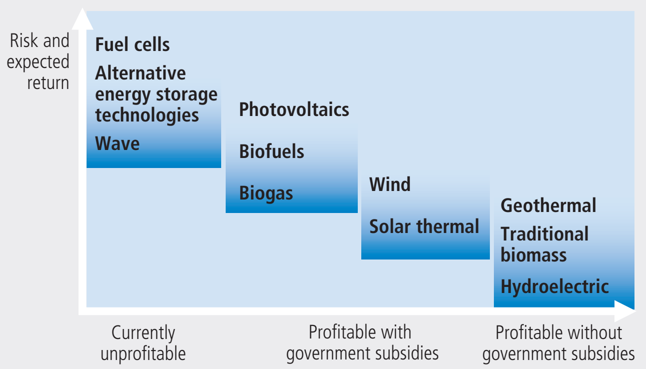
Source: UBS

tions for 2020. Renewable energies that are not cost-competitive depend on political support for R&D and additional investments to become competitive. Accordingly, many alternative energy subsidies mandate annual cost reductions. Long-term investments in energy and energy efficiency technologies are only attractive as long as the technology achieves the mandated cost reductions. In the case of photovoltaics, the industry has so far proven its cost reduction potential, achieving, as a rule of thumb, a 50% cost reduction every decade (see Fig. 5.9).

- Companies may need to overcome a variety of market access barriers in order to achieve growth in new products and technologies. For example, local electricity generation may be difficult to integrate into a country's centralized electricity and supply infrastructure, broad social acceptance may be difficult as has been the case for nuclear power, or new materials, such as carbon fibers in automotive applications, make sense only when combined with a completely different design and manufacturing approach.

Fig. 5.8: Risk-return profile of renewable energy technology

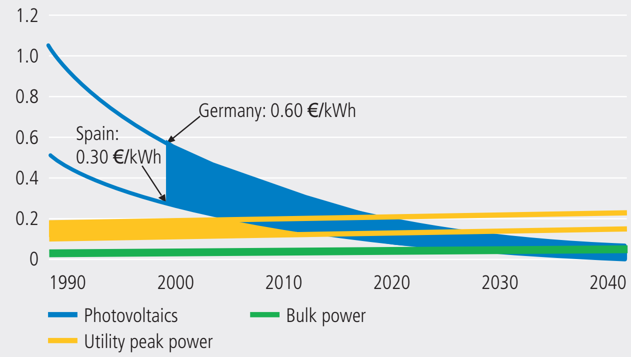
Risk and expected return versus degree of profitability



Note: The groupings in the above figure are generalizations and may not apply to all current situations.
Source: UBS

Fig. 5.9: Historical and projected cost for photovoltaics

In EUR per kilowatt hour



Note: Calculation based on assumption of 900 hours per year of sun in Germany and 1,800 hours per year of sun in Spain.
Source: RWE Energie AG and RSS GmbH

Renewable energy market penetration

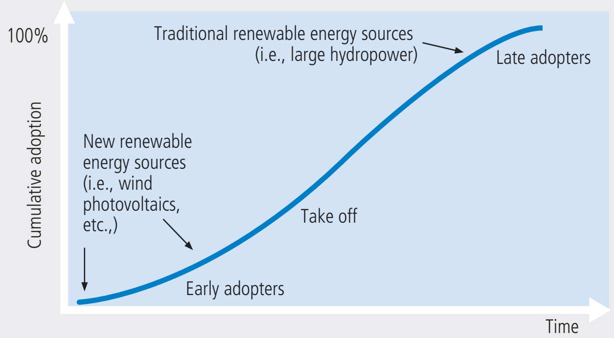
Looking at potential market penetration, most renewable energy and energy efficiency technologies still have a very low level of market penetration (see Fig. 5.10). Most renewable energy technologies group on the bottom left part of the curve, with considerable differences among the various technologies. On the far right side of Fig. 5.10 are hydropower plants, which have been in use for hundreds of years and offer limited potential for further optimization. Existing projects have stable cash flows and defensive investment characteristics.

The earlier the stage, the more important it is to have the knowledge to assess the technological feasibility and potential, and the more the investment has an option-like characteristic. If a technology becomes more advanced other factors become important (for example, mass production is possible and the market will adopt the technology).

Some renewable energies are merely ideas or are in the first phase of research (for example, genetically modified algae that produce cost-efficient petroleum-based products). Fuel cells have moved from testing in the lab to field-testing and quite widespread diffusion of pilot applications. Flow batteries that can economically store and supply large amounts of electricity on demand, enabling the provision of firm capacity from intermittent sources, may just be moving to mass production and wider market adoption. The same is true for large-scale solar thermal plants. Photovoltaics have entered production for the mass market and are in a phase of above-average growth.

Fig. 5.10: Lifecycle of renewable energy technologies

Cumulative adoption versus time



Source: Rogers (1995), UBS

Carbon disclosure project

Institutional and individual investors are becoming increasingly aware of how climate change risk and policies can impact portfolio construction, stock selection, and asset allocation. This trend is perhaps best exemplified by the formation of the Carbon Disclosure Project (CDP), the largest and most visible investor collaboration to collect information on how companies are responding to climate change. Since the first project was launched in 2002, the number of institutional investors supporting the project has increased from 35 to 211, while the aggregate assets under management represented by these signatories have grown from USD 4.5 trillion to more than USD 31 trillion.

CDP began collecting data on greenhouse gas emissions in 2002 with a single global request for information. Companies respond with concrete figures on their carbon emissions, as well as their strategy for managing emissions through techniques such as reduction targets and emission reduction technologies. Although the CDP's initial request included only the largest FT500 companies, the latest round was expanded to more than 2,100 companies. As of 2006, the CDP gathered information from 360 of the FT500 companies (a 72% disclosure rate, up from 41% in 2002), and received responses from 940 companies.

Attention from the investment community on climate change risks has escalated the pressure on corporations to disclose relevant emissions data and their plans for managing their exposure. The disclosure project has also strengthened the perception that due diligence on climate change is now a component of a company's fiduciary responsibility, and can contribute to changing how the capital markets look at carbon risks and opportunities. Companies with low carbon exposure and beneficial products and services might attract additional capital, while companies with high risk exposure might have increasingly limited access to capital. Incentives will increase for companies to more effectively manage their carbon impact, as the CDP information is integrated into mainstream investment research analysis.

Similar initiatives include the Investor Network on Climate Risk (INCR) in the US, or the Institutional Investor Group on Climate Change (IIGCC), which are composed of major pension funds and other institutional investors. The objectives of all of these programs have been to: raise awareness of climate risk as a fiduciary duty; encourage investors to examine climate risks in their portfolios; and use shareholder pressure to improve corporate governance on climate risk.

Financial products

Investors who seek to incorporate climate change risks and opportunities into their portfolios have a number of available options that span a wide range of asset classes (see Fig. 5.11).

Equity-related strategies include underweighting sectors, industries, and companies that are highly carbon intensive and have little potential to adapt (see Fig. 5.5). In addition, there are opportunities, in our view, to directly benefit from climate change mitigation by investing in companies exposed to renewable and low-carbon energy production and energy efficiency. Similarly, investors can target theme funds focusing specifically on climate change mitigation, as well as a range of equity baskets, certificates, and indices on specific investment areas, such as white biotech, photovoltaics, and biofuels. Investors may also access unlisted renewable or energy efficiency companies by investing in the growing number of venture capital firms and private equity funds focused on environmental technology.

Fig. 5.11: Climate change portfolio considerations

Equities	Bonds	Private equity/ venture capital	Real estate	Hedging instruments	Others
Portfolio screening SRI funds Thematic funds Renewable energy and efficiency stocks "Green" hedge funds Certificates	Portfolio screening SRI funds Renewable energy bonds	Environmental venture capital	Improved energy efficiency within property portfolio	Insurance Weather derivatives Catastrophe bonds Emissions indexes	Carbon funds

Source: UBS

Socially responsible investment (SRI) funds and indices are another option, and generally follow three approaches: one that includes only the best companies, one that excludes laggards, and one that focuses on the highest improvement potential (see Fig. 5.12). Although selection criteria for these financial instruments are not purely related to climate change and will likely also include other environmental and social factors, climate change is one of the more important environmental criteria for company selection in the sectors with high carbon risk.

Carbon funds primarily buy and sell Certified Emission Reduction credits. These funds have proliferated rapidly in the last few years, and have been a prime driver of credit prices within the Clean Development Mechanism and Joint Implementation markets. Most of these funds have been established to service the demand for emission allowances among companies looking to meet their quotas, such as under the EU ETS. Access to these funds by individual investors is currently limited.

Emissions index products track the price of carbon allowances in various emissions trading schemes through their exposure to derivatives. Keep in mind, emissions indexes have no effect whatsoever on climate change mitigation, either directly or indirectly. That said, institutional investors can use such an index product as an investment vehicle and also potentially as a hedge against exposure to higher carbon allowance prices. Both individual and institutional investors would likely face substantial political risk from long-only exposure to such an index product because the regulatory framework is still in a development phase. As a result, the price of carbon allowances has been highly volatile since the inception of most emissions trading schemes.

Within the fixed-income markets, investors can reduce their exposure to companies that face heightened credit risk because of future policy measures and un-hedged exposure to severe weather events, such as hurricanes and floods. On the opportunities side of the ledger, governments and project development companies are issuing renewable energy bonds with increased frequency in order to finance specific clean energy projects.

Finally, real estate products with a key focus on climate change are limited to date. However, investors can still benefit within their own personal property portfolio through cost savings generated by energy efficiency improvements, and through the improved rates and terms offered through green mortgages.

Fig. 5.12: Various approaches to SRI products

Source: UBS

Applying the investment framework

Climate change is a highly complex force that will have myriad investment implications, some of which are apparent now, but many of which may not be apparent for decades. Making investments based on climate change criteria is presently difficult because of the limited financial product range and available information. That said, the financial product universe is broadening and the pressure on companies to disclose information that is relevant to climate change and emissions is increasing.

The risk of future climate change events on companies and industries includes heightened regulation, increased impairment of physical property, loss of revenues, erosion of reputation, or some combination of all of these risks. In the event that the business-as-usual energy scenario continues to predominate, investors would be best served by reducing the direct physical risks that climate change will likely have on their portfolio. Even if greenhouse gas emissions are reduced, but not to a level that stabilizes atmospheric concentrations, heightened attention on climate change will likely raise the importance of both the risks and opportunities.

The opportunities related to climate change mitigation fall into two broad categories: products and processes that deliver improved energy efficiency, and development of renewable/low-carbon energy sources. The more incentives that emerge to encourage people to limit greenhouse gas emissions, the greater the outlook for investment opportunities related to climate change mitigation. If investors believe that climate change is an important enough issue, they can immediately and directly alter not only their investment portfolio, but also their lifestyle and behavioral choices. In our view, it is the prospect of individual behavior proliferating on a large scale, combined with more stringent regulation of greenhouse gas emissions, which makes the opportunities related to climate change mitigation a compelling investment case.

Appendix

Response to climate change: adapt or mitigate?

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Response to climate change: adapt or mitigate?

Apart from ignoring it, people have essentially two options for dealing with climate change: react and adapt to climate change events as they develop, or mitigate the impact of climate change through policies and incentives that change behavior.

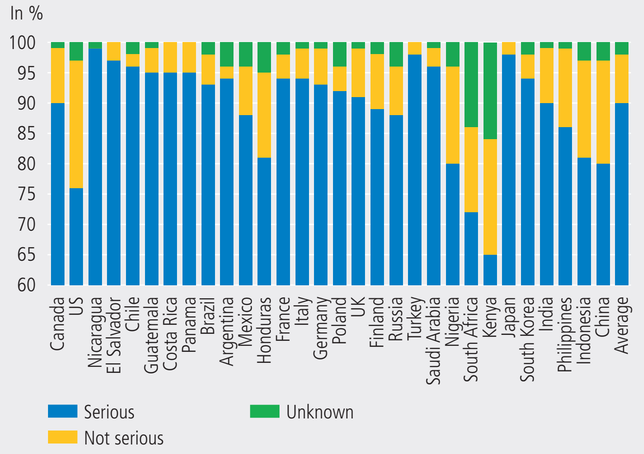
Adaptation

Adaptation involves lifestyle changes to limit the negative impact of climate change on daily living. The potential for adaptation is endless, but involves some degree of disruption and cost. This could mean that people will migrate to higher elevations in the face of rising sea levels, for instance. People might also find it necessary to avoid drought-prone regions near forests: areas which have a higher risk of being engulfed by fire. Development of drought resistant crops, water infrastructure projects (both the distribution of clean water as well as for flood management), and policies to assist resettlement all factor into the category of adaptation.

Adapting to climate change will not involve negative consequences in every instance. As we wrote in chapter 1, some polar and temperate regions will become steadily more inhabitable because of the warmer temperatures there. People in these regions might even find adaptation economically advantageous despite the dislocation that climate change will entail. However, the same models that show how climate change will benefit certain regions also illustrate how other less fortunate regions will be harmed. Here, adaptation is expected to involve some of the more devastating consequences of climate change, such as flooding, forest fires, drought, and the corresponding toll that these natural disasters have on human life, biodiversity, and ecosystems.

Many studies have shown that poor countries, which bear the least responsibility for rising concentrations of greenhouse gases, are the ones that are the most vulnerable and the least able to adapt. Poor countries rely heavily on agriculture, are located in drought-prone regions, and lack institutions and financial capital for managing contingency plans and infrastructure costs. Ultimately, adaptation will likely prove inadequate for addressing the more severe outcomes of climate change because of the uneven distribution of

Fig. A.1: Is the climate a serious problem or not?



Source: Globescan and World Public Opinion adaptation costs. Moreover, those areas that produce the bulk of greenhouse gas emissions are not necessarily the areas that will face high adaptation costs. Nevertheless, adaptation will likely be necessary if mitigation efforts prove unsuccessful. Indeed, as public awareness of global warming increases, so does public support for a mitigation plan (see Fig. A.1).

Mitigation

Mitigation refers to changes in behavior that lead to both an increase in the earth's ability to absorb carbon dioxide and a reduction in present and future greenhouse gas emissions. Since carbon dioxide represents three-quarters of total greenhouse gas emissions, curbing them is an integral part of any mitigation effort. Carbon dioxide emissions can be viewed as a function of:

1. population size,
2. per capita income,
3. energy intensity of economic output, and
4. carbon intensity of energy consumption.

Climate change and insurance

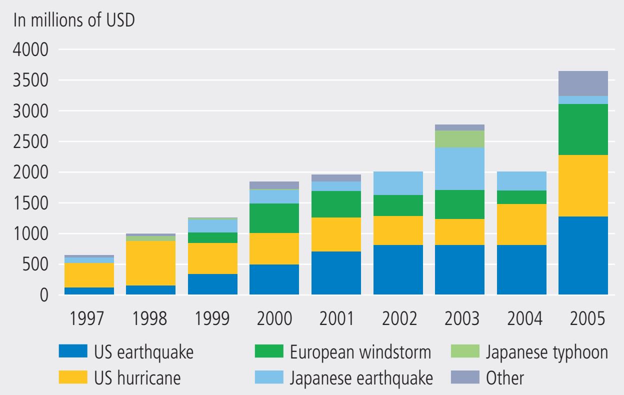
The insurance industry will likely influence how people adapt to climate change through its role as a conduit for risk management. For instance, a predicted consequence of global warming is severe flooding, brought about by greater and more intense precipitation in certain coastal communities. Insurance companies are beginning to assign a price to this heightened risk by raising premiums for flood insurance. Given the limited information available to model potential damages and their likelihood, there is a significant amount of uncertainty regarding how well insurance markets will function to encourage adaptation to climate change.

Extreme weather events threaten the long-term earnings prospects of the insurance industry. According to Munich Re, the insurance industry faced record claims of USD 30 billion during 2004 because of hurricanes and severe weather in the US and the Caribbean. The following year's hurricane season shattered this record with more than USD 83 billion in claims, following hurricanes Rita and Katrina. There were more hurricanes in 2005 than in any other year since records were started in 1851.

After assessing the probability and size of expected damages, insurance companies can choose to withdraw from a market entirely, charge higher premiums, or sell catastrophe bonds. These spread the risk of large-scale disasters among a wide pool of investors, thereby removing the risk from insurance company balance sheets (see Fig. A.2). Inflation-adjusted economic losses from catastrophic events rose to USD 45 billion in 2004, and USD 78 billion in 2005, according to Swiss Re (see Fig. A.3). As a result, catastrophe bonds and other methods to remove risk from the balance sheet will likely grow in importance.

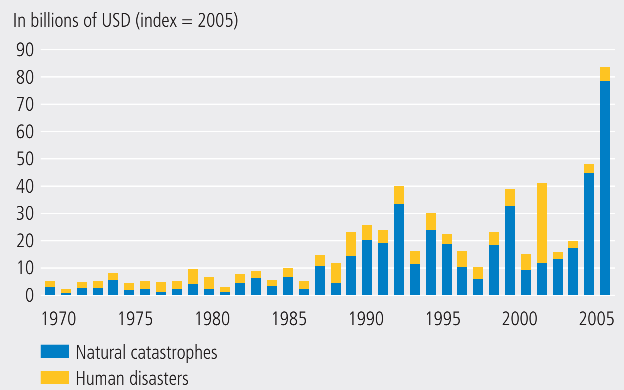
There are a number of risks in addition to property loss that may impact insurance claims, although losses attributable to these additional factors are difficult to quantify. These risks include business and supply-chain disruptions, loss of utility services, equipment breakdown arising from extreme temperature events, and data loss from power surges or outages. Extreme weather events can breach pollution containment, leaving industries open to liability, and power outages disrupt manufacturing and services. Adverse weather conditions also directly impact human health and is an issue for life insurers. Therefore, insurance companies will play an increasing, but as yet undetermined, role in adapting to the new environmental realities of climate change.

Fig. A.2: Risk capital by specific peril



Note: "Other" perils include European hail, Monaco earthquake, Puerto Rico hurricane, Taiwan earthquake, third-party casualty liability and bonds for which the peril was not disclosed.
Source: MMC Securities

Fig. A.3: Inflation-adjusted insured catastrophe losses



Source: Swiss Re, Sigma Insurance Research

Emissions reductions require changes to at least one and potentially even all of these factors. For our purposes here, we are concerned with reducing the energy intensity of economic output and reducing the carbon intensity of energy consumption. These last two factors would involve raising energy efficiency in production and consumption behavior, as well as switching to renewable forms of energy and natural gas. These two factors also formed the basis of our analysis of the four principal activities that contribute to greenhouse gas emissions in chapter 4.

The policy options for mitigating climate change can be classified as either "command and control" or "incentive-based." The "command and control" approach involves emissions and technology standards, and relies on the government to mandate and enforce legal guidelines. By contrast, incentive- or market-based methods rely not only on the government to set overall goals and guidelines, but also depend on firms and households responding to usual market incentives to reach these goals. In so doing, incentive-based mitigation, using taxes, subsidies, and emissions trading, is achieved in a more cost-effective manner. Fig. A.4 shows the timeline of progress on coordinated international policies for addressing climate change.

Fig. A.4: Major climate change policy milestones

1988	UNEP and WMO establish the Intergovernmental Panel on Climate Change (IPCC), which produces regular scientific and technical assessments on climate change.
1992	The U.N. Framework Convention on Climate Change is agreed on at the Earth Summit in Rio de Janeiro, Brazil. The Convention enters into force in 1994.
1995	The IPCC Second Assessment Report concludes that the balance of evidence suggests a discernible human influence on the global climate.
1997	Adoption of the Kyoto Protocol to the UN Climate Convention.
2001	The IPCC Third Assessment Report finds stronger connections between human activities and the global climate system. The United States announces that it will not become a Party to the Kyoto Protocol. Other signatories adopt the "Marrakesh Accords," a set of detailed rules for the implementation of the Kyoto Protocol.
2004	Russian Federation ratifies the Kyoto Protocol, triggering its entry into force in February 2005.
2005	First meeting of the Parties of the Kyoto Protocol takes place in Montréal, Canada.
2007	The IPCC Fourth Assessment Report to be published.

Source: WRI, UBS

Emission & technology standards

An emission standard sets a specific limit for the amount of a pollutant that a source can emit, while a technology standard mandates that polluters adopt a specific technology, equipment, or process. Regulatory authorities mandate an emission level, and everyone is required to comply or else run the risk of fines. Tailpipe emission standards for automobile manufacturers are a typical example of an emission standard, whereas requiring the public sector to purchase alternative-fueled vehicles is an example of a technology standard.

Standards are viewed as potentially rather costly, as they are usually designed as a "one size fits all" policy, and because they do not take into account the differences among emitters in terms of their cost-effectiveness at reducing emissions. While certain firms might incur very high costs to achieve the standard, it gives little incentive for other firms with low abatement cost technology to exceed the reduction targets.

Hence, while standards might be an effective method for reducing emissions (most current environmental regulation is based on standards), they are not necessarily the most cost-efficient, as emissions are not always reduced where it is cheapest. Nor is it guaranteed that standards will reduce greenhouse gas emissions. It is possible, for example, that both the number of cars and the miles people drive will increase, irrespective of any emission standards that lower the greenhouse gas emissions intensity of automotive travel.

Emission taxes & subsidies
Another policy for mitigating the risks of climate change involves levying a tax on greenhouse gas emissions. However, in the case of taxes no one is legally bound to reduce emissions, as they are with standards. Ultimately, it is the degree of sensitivity among consumers and producers to changes in price that determines how much effect a tax has on reducing emissions, and who has to pay the largest share of the tax (i.e., producer or consumer).

For example, suppose a government imposes a carbon dioxide emissions tax on petrol. If drivers opted to buy the same amount of petrol, irrespective of the price, then carbon dioxide emissions would remain unchanged and drivers would absorb the full cost of the tax. Meanwhile, the fuel seller would have little incentive to reduce the carbon-dioxide intensity of petrol. In the case where consumers are more sensitive to price changes, taxes encourage technological advances to reduce a polluter's tax liability and abatement costs. Taxes provide an incentive for some firms to reduce emissions as much as possible, whereas, for other firms, the cost of mitigation might be so high that it is cheaper to simply pay the tax. This makes a tax more cost effective than an emission standard. A tax also offers the benefit of capping the total cost of abatement at the total level of emissions and the tax rate.

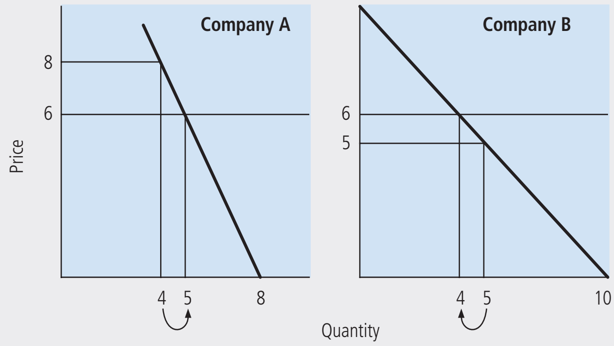
In any event, levying emission taxes is apt to be both politically and administratively difficult, given the large variety of emission sources. Conversely, emission subsidies are the reverse of a tax and can be financed with the revenue that is generated from emission taxes. For example, the private sector could be awarded subsidies, in the form of tax breaks for renewable energy generation and R&D, to lower greenhouse gas emissions.

Emissions trading in detail

Fig. A.5 illustrates how emissions trading works in a hypothetical situation. The objective is to reduce the two companies' emissions by half, from an unregulated level of 18 metric tons to a cap of 9 metric tons. To achieve a 50% reduction in emissions, companies A and B are allocated emissions permits of 4 and 5 metric tons, respectively, which is exactly half of their original emissions. Because company B can reduce emissions more cheaply than company A, there is an incentive for both to trade the rights to emit. Company B will have a surplus of emissions because of its more cost-effective techniques, while company A will have a deficit. Company A is better off buying permits below $8, while company B gains from selling permits above $5. The two companies will continue to trade until their incremental emission reduction costs are equal at $6. At this point, company A emits 5 metric tons, which is larger than the 4 metric tons initially allocated to it, while company B emits 4 metric tons, which is less than the 5 metric tons it was allocated. Meanwhile, society achieves the goal of capping total emissions at 9 metric tons.

Fig. A.5: Hypothetical emissions trading arrangement

Price of carbon emissions versus the quantity of carbon emissions



Source: UBS WMR

Emissions trading

The newest development for reducing greenhouse gas emissions, and the one that is gaining increased support from the international community, is a concept known as emissions trading. At first blush, trading the right to emit is a rather vague concept. Trading goods, like car parts and video games, makes intuitive sense because there is something tangible to hand off in the trade. Emissions, on the other hand, are intangible for the most part.

In emissions trading, scientists and governments jointly establish a cap on greenhouse gas emissions. Emissions rights are then apportioned to the leading polluters in the form of permits or certificates. With these permits in hand, polluters engage in trading activity, buying and selling emission rights on an exchange, depending on whether it is cheaper to buy permits and pollute, or sell permits and reduce emissions. Thus, the system allows for firms to exceed their individual allowances by buying surplus permits from firms that reduce emissions, while capping total allowances. The price of permits will rise if demand exceeds supply at a given price, and will fall if there is a surplus of permits available (see box on emissions trading on page 94).

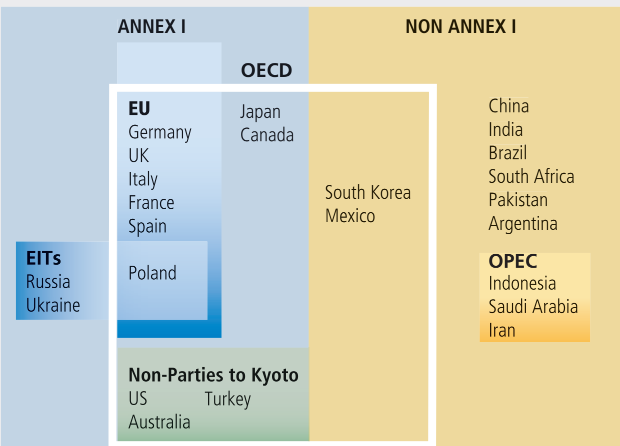
As a mitigation strategy, trading emissions has the following advantages: it is more cost-effective than emission standards because those companies that can reduce emissions most cheaply will produce the most emissions reductions; it is more politically viable than emission taxes; and it provides incentives for technological innovation. Its drawbacks include potential difficulties in monitoring and enforcement, especially in an international setting, as well as the political and practical challenges associated with first determining and then assigning the initial allocation of permits (see box on carbon trading on page 96).

Kyoto Protocol

The Kyoto Protocol is an international agreement between a consortium of developed and transition economies (see Fig. A.6) that sets greenhouse gas emission reduction targets and specifies a framework for attaining these reductions. The protocol seeks reductions of six principal greenhouse

Fig. A.6: Top greenhouse gas emitters

By region and organization



Source: WRI, UNFCCC

gases: carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride. The current agreement encompasses the period from 2008–2012, during which time the member countries are required to meet their respective reduction targets.

The protocol took effect in February 2005, and as of January 2007, 164 countries had ratified the agreement, with the notable exceptions of Australia, Turkey, and the US. Of those that have ratified the protocol, 35 countries are required to reduce their greenhouse gas emissions. Developing countries are not obligated to reduce greenhouse gas emissions under the Kyoto Protocol because of their lower per capita emissions, lower levels of per capita income, and smaller contribution to the accumulated greenhouse gases in the atmosphere. In the aggregate, the protocol aims to reduce annual average greenhouse gas emissions to 5% below 1990 levels (as defined in Annex B of the protocol). However, most developed nations are required to pare back emissions by about 8%.

To achieve the reduction targets in the most cost-effective manner, the Kyoto Protocol sanctions three flexible mechanisms: international emissions trading, joint implementation (JI), and the Clean Development Mechanism (CDM).

The European Union Emissions Trading Scheme

The Kyoto Protocol sanctions emissions trading as one mechanism to minimize the global cost of reducing greenhouse gas emissions. Two emissions trading schemes have emerged: the European Union Emissions Trading System (EU ETS) and the Chicago Climate Exchange (CCX). Although the US government is not a signatory to the Kyoto Protocol, some US corporations, municipalities, and states have voluntarily agreed to emissions reductions and to participate in emissions trading systems, such as the CCX. In fact, California, the 12th largest greenhouse gas emitter in the world, put forward a plan in August 2006 to curb emissions by 25% by 2020.

Phase I of the EU ETS came into effect on 1 January 2005 and allocated emissions to more than 12,000 specific installations across 25 member countries (primarily within the power generation and industrial sectors), representing 45% of total EU carbon dioxide emissions. Companies trade European Union Allowances (EUAs) to meet the allocated goals, which were set by individual EU governments in their National Allocation Plans (NAP) and were based on current estimated emission levels.

Since inception, the market price for traded EUAs has experienced significant volatility (see Fig. A.7). Carbon prices declined sharply in May 2006, following the release of emissions results for 2005. The results showed that the overall system produced far fewer carbon dioxide emissions than the quota system permitted (although some countries, such as the UK and Spain, did exceed their emissions quota), resulting in an overall excess supply of emissions credits. However, this surplus was not the result of absolute emission reductions. Instead, individual member states and their NAPs had overestimated the initial allocations.

This has increased political pressure to tighten allocations for Phase II of the EU ETS, which begins in 2008 and coincides with the Kyoto Protocol's first commitment period. In the 2008-2012 commitment period, the price of EUAs will depend on the availability of credits from Russia and elsewhere, on the rules that ultimately apply to European domestic reductions by country, and on the rules governing European actions in total. Failure to meet targets through mitigation or purchasing credits leads to a fine of EUR 40 per metric ton in Phase I, rising to EUR 100 per metric ton in Phase II. Additionally, prices are likely to be determined by the price and availability of Certified Emission Reductions (CERs), developed through projects originating from the Clean Development Mechanism and joint implementation (see below).

Fig. A.7: European carbon dioxide futures prices

In EUR per metric ton of carbon dioxide

Source: European Energy Exchange, Bloomberg

Emissions trading
Emissions trading allows Annex 1 nations (defined as developed and transition economies that have agreed to emission reductions under the protocol) to buy and sell emission permits among themselves. Under this mechanism, countries that are able to cut emissions beyond their obligations could sell their excess emission permits to those that do not fulfill their target reductions.

Joint implementation
Joint implementation (JI) allows Annex 1 countries to earn emissions reduction units by participating in projects jointly with other Annex 1 countries. For instance, a JI project might involve replacing an inefficient coal-fired power plant in the Ukraine with a more energy-efficient power plant that generates both heat and power.

Clean Development Mechanism
The Clean Development Mechanism (CDM) allows Annex 1 countries to earn emission reduction credits by funding projects in non-Annex 1 countries (i.e., developing countries that are not required to undertake emission cuts but that participate in the Kyoto Protocol as recipients of CDM projects). Credits created under the CDM are known as certified emission reductions (CERs).

An example of a CDM project is the August 2006 agreement between two Chinese chemical companies and a group of mostly European and Asian corporations. For this project, the emission reductions would be accomplished by installing an incinerator that decomposes hydrofluorocarbons. Only a small proportion of the funds will be dedicated to purchasing the incinerator. The rest of the financing will be channeled into a Clean Development Fund that will pay for other emission reduction plans and renew-

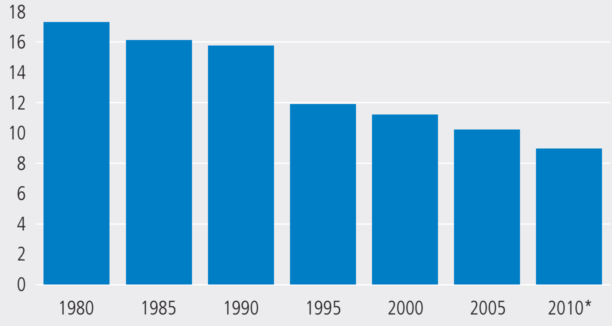
Acid rain, ozone holes, and climate change

There have been many opportunities to test the various mitigation techniques for pollution abatement. Two of the most prominent and successful examples of environmental policy are the 1990 US Clean Air Act Amendment and the 1987 Montréal Protocol on Substances that Deplete the Ozone Layer. The Montréal Protocol is an international agreement to phase out the production of harmful chemicals that deplete the earth's ozone layer. This is an example of both a zero emissions standard and a technology standard. It proved practicable because technological substitutes were available and because there were a small number of principal polluters: as a result, the amounts of certain ozone depleting substances have begun to level off. Success required international agreement, a limited number of polluters, exceptions where solutions were not available, and provisions to help developing countries manage the transition.

The US government passed an amendment to the Clean Air Act in 1990, which, among other things, provided for a tradable allowance system for sulfur dioxide to reduce acid rain. The amendment also takes into consideration the emissions that originate in Mexico and Canada and drift into the US and vice-versa. At its core, the Clean Air Act is a cap-and-trade mechanism within the confines of a strictly regulated "command and control" framework to reduce emissions. The cap on sulfur dioxide is set and enforced by the government, leaving the problem of how to reach the target up to the polluters. Those polluters who find themselves exceeding emissions quotas can either buy permits on the Chicago Board of Trade or they can pursue technology to reduce abatement costs. This program, combined with other policies to reduce mobile point source emissions from cars through emission and technology standards, has produced a dramatic improvement in US air quality standards (see Fig. A.8). An important factor contributing to the success of the Clean Air Act was the fact that the system could be confined to a few large point sources (basically coal-fired utilities), which had reliable monitoring systems for emissions.

Fig. A.8: Sulfur dioxide emissions in the US

In million short tons of sulfur dioxide



Note: * = Sulfur dioxide cap set at 8.95 million short tons in 2010, a level of about one-half of the emissions from the power sector in 1980.
Source: US Environmental Protection Agency

able energy projects in China. The project is designed to achieve greenhouse gas emission reductions equivalent to 19 million metric tons of carbon dioxide each year. The project sponsors can use the CERs created from this transaction to meet their emission reduction targets.

While the Kyoto Protocol represents the most comprehensive global effort to address climate change, it is not free of criticism. For instance, some question why large developing economies are exempt from emissions reduction targets. Others question the validity of certain projects that produce emission credits. For instance, some are skeptical of reforestation projects, since carbon sequestered in forests could easily be released through anthropogenic or natural actions. Lastly, since the Kyoto Protocol is an international agreement between sovereign nations, many are concerned about the overall effectiveness and about the costs of monitoring and enforcing its implementation.

Glossary

Additionality:
Joint implementation and Clean Development Mechanism programs must show that they result in greenhouse gas emission reductions that are additional to those that would otherwise occur.

Adaptation:
In the context of climate change, refers to adjustments in natural or human systems in response to actual or expected climate stimuli or their effects, which moderates harm or exploits beneficial opportunities.

Annex I countries:
Developed countries (those belonging to the Organization of Economic Cooperation and Development, as well as economies in transition) that have accepted a non-binding commitment to reduce greenhouse gas emissions under the Kyoto Protocol.

Annex B countries:
Countries that are legally bound to specific emission reduction targets and emissions caps under the Kyoto Protocol.

Anthropogenic:
Outcomes that originate in human activity.

Atmosphere:
The envelope of gases surrounding the earth and bound to it by the earth's gravitational attraction; subdivided into layers: the troposphere, the stratosphere, the mesosphere, and the thermosphere.

Biofuel:
A fuel produced from dry organic matter or combustible plant oils.

Carbon dioxide (CO_2):
A naturally occurring gas that is also a byproduct of burning fossil fuels, land-use changes, and various industrial processes; the principal anthropogenic greenhouse gas; regulated as a greenhouse gas under the Kyoto Protocol.

Carbon sequestration:
Long-term storage of carbon or carbon dioxide in a carbon sink; often discussed in the context of climate change as capturing carbon dioxide from energy use before it is released into the atmosphere.

Carbon taxes:
A surcharge or levy on the carbon content of oil, coal, and natural gas consumption; intended to discourage the use of fossil fuels and reduce carbon dioxide emissions.

Carbon trading:
See emissions trading.

Chlorofluorocarbons:
Organic compounds that contain carbon, chlorine, and fluorine atoms; widely used as a coolant, solvent, packaging material, insulation, and aerosol propellant; regulated under the 1987 Montréal Protocol to protect the ozone layer.

Clean Development Mechanism (CDM):
Projects that are undertaken in developing countries to promote sustainable development and to satisfy greenhouse gas emission reduction commitments of Annex I countries; increases flexibility in terms of where emissions are reduced; projects must show additionality.

Climate:
Long-term average weather conditions in a region, including the frequency of intense weather. Climate is not the same as weather.

Climate change:
According to the United Nations Framework Convention on Climate Change, "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods."

Climate forcing:
Changes to the climate system that lead to a radiative climate response, either positive or negative; examples include changes in solar energy output, volcanic emissions, deliberate land modification, or anthropogenic emissions of greenhouse gases, aerosols, and their precursors.

Cogeneration:
The use of waste heat from steam or electricity generation for industrial processes or district heating; raises fuel efficiency; see also trigeneration.

Combined cycle:
A power production system that allows for more than one thermodynamic cycle; for example, a gas-powered turbine generates electricity and the waste heat is then used to make steam, which is used in a second process to generate additional electricity.

Deforestation:
The removal of forested areas; includes clearing land for agriculture, residential and industrial use, as well as harvesting trees for building materials and fuel.

Deregulation:
Removal of government restrictions on business and individuals, often to increase competition.

Discount rate:
An interest rate that is used to determine the present value of an item in the future.

Economies in transition:
See transition countries.

Ecosystem:
A system composed of the interaction between a biological community and its environment.

Emissions:
In the context of climate change, generally refers to greenhouse gases.

Emissions allowance:
The total amount of emissions permitted to a source during a given time period; created and distributed by a regulatory body.

Emissions trading:
A market based system that allows companies flexibility to achieve emissions reductions; considered more cost effective than emissions standards.

Externality:
Occurs when someone's actions generate a cost or a benefit for someone else, the value of which is not reflected in the market price

Fossil fuel:
Carbon-based fuels formed in the ground over very long periods of time; includes coal, oil, and natural gas.

Free market:
A market that allows prices to be determined through the interplay of unregulated supply and demand; the opposite is a regulated market.

Fuel cell:
An electrochemical conversion device, similar to a battery, that combines oxygen and hydrogen to produce electricity, heat, and water.

Global warming:
A steady and persistent increase in the earth's average surface temperature due in part to the increasing concentrations of anthropogenic greenhouse gases.

Global warming potential:
A time-dependent weighting of the heating or cooling power of a specific greenhouse gas (see also climate forcing) relative to that of carbon dioxide.

Greenhouse effect:
The infrared radiation that is absorbed and reradiated by atmospheric gases, such as water vapor and carbon dioxide. Without this effect, surface temperatures on the earth would be 33 °C (60 °F) cooler than at present.

Greenhouse gases (GHGs):
Gases that trap the sun's heat in the earth's atmosphere, producing the greenhouse effect; includes carbondioxide, methane, ozone, nitrous oxide, sulfurhexafluoride, hydrofluorocarbons, perfluorocarbons, chlorofluorocarbons, and water vapor.

Hydrofluorocarbons:
Developed to replace chlorofluorocarbons; regulated as a greenhouse gas under the Kyoto Protocol.

International Energy Agency (IEA):
An intergovernmental organization founded during the 1973–74 oil crisis by the Organization for Economic Cooperation and Development (OECD) with the aim of promoting energy security, economic development, and environmental protection.

Infrared radiation:
Invisible radiation that is situated beyond the red end of the spectrum.

Intergovernmental Panel on Climate Change (IPCC):
Established in 1988 by the World Meteorological Organization and the United Nations Environment Programme to assess scientific, technical and socio-economic information relevant for the understanding of climate change, its potential impacts and options for adaptation and mitigation.

Joint implementation:
Projects that are undertaken by Annex I countries to satisfy greenhouse gas emission reduction commitments within Annex I countries; increases flexibility in terms of where emissions are reduced; projects must show additionality.

Kyoto commitment period:
The period between 2008 and 2012, during which, Annex B countries are required to achieve their emission reduction targets.

Kyoto Protocol:
An agreement under the auspices of the United Nations Framework Convention on Climate Change, which assigns mandatory greenhouse gas reduction targets for signatory nations.

Methane (CH_4):
The major constituent of natural gas; results from the decomposition of plants and other organic compounds; primary sources of methane include landfills, coal mines, paddy fields, natural gas systems, and livestock; regulated as a greenhouse gas under the Kyoto Protocol.

Mitigation:
To lessen in force or intensity, to make less severe.

Nitrous oxide (N_2O):
A byproduct of burning fossil fuels and the manufacture of fertilizers; regulated as a greenhouse gas under the Kyoto Protocol.

Non-Annex I countries:
Developing countries that are not bound to reduce greenhouse gas emissions under the Kyoto Protocol.

Passive house:
A house that achieves thermal comfort using the lowest possible designated energy for heating.

Parts per million/billion:
A measure of concentration; in the context of climate change, this refers to concentrations of atmospheric greenhouse gases.

Perfluorocarbons:
A byproduct of industrial process and manufacturing activity; regulated as a greenhouse gas under the Kyoto Protocol.

Photovoltaics (PV):
Conversion of solar energy, or light, into electricity.

Regulated market:
The provision of goods or services using an arm of the government; often includes natural monopolies such as telecommunications, water, gas, and electricity supply.

Renewable energy:
Energy sources that instead of being destroyed when their energy is consumed, are constantly renewed; includes sunlight, wind, waves, water flow and biological process.

Sequestration:
See carbon sequestration.

Stranded investment:
In addition to physical plant closure, financial impairment that results when power plants are unable to generate sufficient operating income to pay for initial capital and financing costs.

Stratosphere:
The region of the atmosphere above the troposphere and below the mesosphere.

Sulfur hexafluoride (SF_6):
A byproduct of electrical equipment manufacturing; one of the most potent greenhouse gases and regulated under the Kyoto Protocol.

Transition countries:
Countries that are transitioning from a planned to a free-market economy.

Trigeneration:
A power production process that derives three forms of energy from a fuel source; in addition to power generation, waste heat is used to produce heating and cooling; raises fuel efficiency; also known as combined, heating, cooling, and power generation; see also cogeneration.

Troposphere:
The region of the atmosphere extending from the earth's surface to the lower reaches of the stratosphere.

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