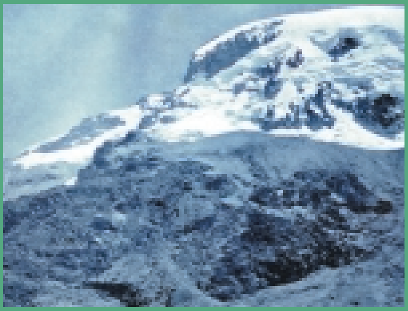
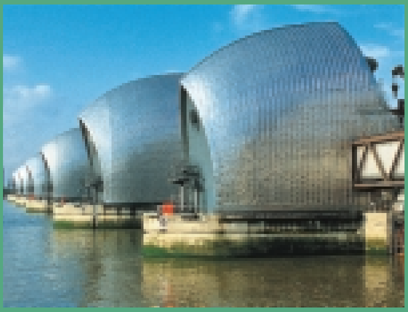
The Ninth Zuckerman Lecture

Sir David King KB ScD FRS

Chief Scientific Adviser to the UK Government and Head of the Office of Science and Technology





The Science of Climate Change: Adapt, Mitigate or Ignore?

The Annual Zuckerman Lecture

Each year an internationally eminent figure in the science world is invited to address the British scientific community at the Zuckerman Lecture. The lectures are named after the first government Chief Scientist, Lord Zuckerman.

The Lord Zuckerman was one of the most distinguished scientists of this century and was at the heart of British science for over sixty years. He studied medicine in South Africa and in the UK before becoming the Zoological Society's Prosector or Research Anatomist in London. He taught at Yale and Oxford in the 1930s and was made Professor of Anatomy at the University of Birmingham.

During the Second World War he was Scientific Adviser to Combined Operations and on strategic planning. He became Chief Scientific Adviser to the Ministry of Defence in 1960 and was the Government's first Chief Scientific Adviser from 1964 to 1971. He was Secretary to the Zoological Society of London from 1955 to 1977 and President from 1977 to 1984.

Solly Zuckerman was created a life peer in 1971 and took the title Baron Zuckerman of Burhan Thorpe. He died in April 1993. Lord Peyton of Yeovil has written a biography of Lord Zuckerman (A scientist out of the ordinary - Solly Zuckerman by John Peyton [Pub. John Murray 2001 ISBN 071956283X]).

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Foreword

I was particularly delighted to welcome Sir David King KB ScD FRS – The Chief Scientific Adviser to HM Government and The Head of the Office of Science and Technology, to deliver the 9th Zuckerman Lecture at The Royal Society on 31st October 2002. It was particularly timely that he should share his thoughts on the environment with us in a year when it has been at the focus of the World's attention as a result of The World Summit on Sustainable Development, which South Africa hosted in August 2002.

Scientific and technological advances, innovation and enterprise are crucial to reconciling economic growth and sustainability. Global warming is a particularly important example of where development along current lines is at odds with the environment. In his speech, Professor King addressed the crucial role that science has to play in understanding and mitigating climate change, and in adapting to its effects.

Environmental policy raises many complex and difficult decisions which require careful analysis and innovative solutions. The Chief Scientific Adviser's words certainly stimulated a lively discussion both after the lecture and over supper.

My thanks go to The Foundation of Science and Technology and to the sponsor for their help in organising what was a fascinating lecture.

The Ninth Zuckerman Lecture

THE SCIENCE OF CLIMATE CHANGE: ADAPT, MITIGATE OR IGNORE?
By Sir David King KB ScD FRS

MOUNTAIN ICE

Quite recently I was in the U.S.A at the Harvard University Kennedy Centre and was privileged to participate in a discussion with a group of top "Ice Scientists" about the state of ice on the globe. One of the participants was Lonnie Thompson, from The Ohio State University.

Lonnie, no longer a young man, flies around to the highest ice caps around the world and takes deep ice cores from them. These ice cores provide a measure backwards in time of one aspect of the history of the globe. Lonnie and his team are now speeding up the process of collecting, analysing and storing these ice cores as quickly as possible in order to preserve these unique climate histories which are at risk.

What particularly struck me was a photo that Lonnie took on a visit to Mount Kilimanjaro. This caught my attention for two very different reasons. One is personal: my 18-year-old daughter is currently having a gap year in Tanzania and she happens to be teaching in a school in the foothills of this mountain, and this is the view she sees every day. The second is the prognosis for the ice cap which is still so clearly visible on the mountain top. It’s there all the year round – this was a summer picture and it was taken in 1998. However, a second picture of the same peak taken in 1917 shows a very clearly visible difference in the extent of that ice cap; roughly eighty per cent of the ice has been lost over that 80-year period.

Lonnie has dated the Kilimanjaro ice cores back 11,700 years. The cap goes back to the last Ice Age; he has calculated that when the 1917 photo was taken there was 12.1 sq km of ice on that mountain top. There is now roughly 2.6 sq km left, and by extrapolating forward a series of data points over time from 1917 on a linear graph he predicts that the ice cap will disappear in around 2015. The boundary of the ice cap is currently moving back up the mountain at an alarming rate.

DEVELOPMENT OF SCIENTIFIC UNDERSTANDING

The first question that I am going to address is, why is this happening? Ice scientists, like most other scientists, disagree with each other and challenge each other and sometimes the disagreements are quite radical. So while Lonnie has a particular view of the explanation for Kilimanjaro, there are other scientists who believe that what is happening at Kilimanjaro is yet to be explained. What I’d like to do is go back in time to give you a brief history of the study of the composition of the earth’s atmosphere. I will present roughly 40-year snapshots in time to establish just what and for how long we have understood some of the problems associated with climate change.

My story starts in 1827 with the great French mathematician Fourier. He is very well known today to physical chemists like myself for his widely used Fourier Transform. It was he who first coined the term "Greenhouse Effect" and provided an explanation for the relatively small temperature difference between daytime and night-time on the earth, and the development of a climate that was, amongst other things, suitable for us human beings to develop in. Light from the sun comes through the atmosphere with particularly efficient penetration of the visible and ultraviolet or high-energy, end of the spectrum, and directly warms the earth. What radiates back upwards is very largely infra-red radiation, and a significant portion of that radiation that goes back from the earth towards space is absorbed in the atmosphere. The atmosphere therefore retains some of the radiated heat and all that Fourier said was that the global climate was therefore determined by the balance of these processes. Return radiation from the atmosphere keeps the earth warmer by about 30°, and also keeps night-time temperatures reasonable. This is the greenhouse effect: I want to emphasise that the greenhouse effect is benign, it is what we need.

But it must also be clear that our global temperature is a sensitive balance between heat loss and heat gain. Gases trapped in the atmosphere effectively determine local and global temperatures, and hence are crucial for our climate.

Now lets skip forward to 1860, when the British scientist, Tyndall, comes into the picture. It was Tyndall who explained why we look at a blue sky in the day time and a red sky at sunset. Of relevance to us here, he measured the absorption of light energy by carbon dioxide and water vapour, and suggested that it was variations in carbon dioxide levels that brought about the various ice ages. The cyclical occurrence of the ice ages can be measured from ice cores from Antarctica dating back 450,000 years: our British Antarctic Survey has played a leading international role in this work. Temperature changes over this time span are estimated as between 5-10 degrees centigrade variation; the lower temperatures signal the ice ages, and the higher temperatures are the warm periods such as the present. Tyndall attributed these temperature changes to changing carbon dioxide levels in the atmosphere, probably related to changing populations of living organisms. This implies a dynamic process over a long timescale. The Tyndall Centre at the University of East Anglia, which I am told by many atmospheric scientists, including those at the Kennedy Centre, is now the leading climate change centre in the world, was established there quite recently within the School of Environmental Sciences. It was Solly Zuckerman's vision and effort that gave rise to that school. In the late 1950s he pressed for it to be established, and it is gratifying to note at this lecture which honours him that the School of Environmental Sciences at UEA has already established a tremendous world-wide reputation.

Moving on from Tyndall, we come in 1896 to the Swedish chemist Arrhenius, a familiar name to all chemists who have studied the rates of chemical reactions. Arrhenius made the first attempt to estimate quantitatively the effect of carbon dioxide on global average temperatures. Using a simple physical model, he estimated that if the level of carbon dioxide in the atmosphere were to be doubled the average global temperature would rise due to Fourier's greenhouse effect by an estimated 5-6 degrees Centigrade. Interestingly that estimate made in 1896 is not very different from the most modern attempts to calculate the temperature change due to increasing carbon dioxide levels in the atmosphere.

Let me now fast forward another forty years to 1938 to an address to The Royal Society by the British meteorologist Callender, who was the first person to claim that there was evidence for global warming. He had collected together data from 200 weather stations around the world over the period from 1880 to the 1930s. He presented his conclusions here at The Royal Society but what I have to report is that the Fellows of The Royal Society duly challenged his conclusions and the outcome was that no more was heard of Callender's work for some time. The reason is that if you look at the measurements and the noise level associated with them, it was quite a difficult conclusion to justify at that time.

I am going to move on to 1988 when James Hansen, a leading NASA scientist, told the US Senate Energy Committee, that he was "99% certain" that global warming was occurring and was linked to fossil fuel burning. That created quite a stir around the world, and as a result there was general acceptance that this was a major problem that needed to be dealt with. It is worth noting that as far back as 1965 the White House first ordered a study into the effect of fossil fuel burning on climate change and the UN picked this up in 1970. By 1980 the US National Academy of Sciences was estimating that doubling the carbon dioxide level would change global temperatures by 1.5 to 4.5 degrees centigrade, quite close to what Arrhenius had estimated 84 years earlier. It is interesting that President Bush in 2001 once again went back to the National Academies of Sciences and asked them if there is a problem with our climate. He got much the answer that I am going to deliver to you now.

The Inter-Governmental Panel on Climate Change (IPCC) has had a tremendous influence in formulating and correlating scientific opinion on this question. It was formed initially through the World Meteorological Organisation and the UN Environment Programme in 1988, and within a short time, by 1990, they had produced their first report, a joint report prepared by 175 scientists from 25 countries. Their work continues to the present day. They concluded that human activities were causing an increase in global temperatures and predicted a further increase by 1 degree centigrade by 2025 and 3 degrees centigrade by 2100; subsequent reports have always seen an increase in these estimates. It is worth noting that their first report, in 1990, was followed by the hottest decade to date, with seven years recording successively the highest global average temperatures in close agreement with the predictions of this report.

CURRENT STATE OF CLIMATE CHANGE SCIENCE

Carbon Dioxide Levels over the last 60,000 Years

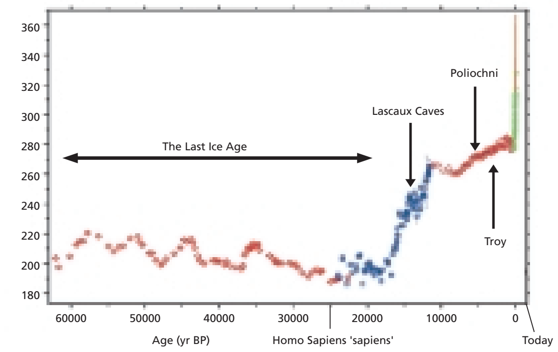


Figure 1

Source: School of Enviromental Science, UEA

Let me come to what I consider to be the current state of the science. A very detailed history of changes of atmospheric greenhouse gas levels over many millennia has been obtained from ice cores due to annual precipitation and compacting of snow on ice caps, sheets and glaciers around the world. Carbon dioxide is the main gas at work here. The results of measurements covering the last 60,000 years are shown in figure 1. Up to the end of the last ice age, carbon dioxide levels varied within the range 190 to 220 parts per million (ppm). Then, between 17,000 and 12,000 years ago the level rose to about 270 ppm. This rise marked the end of the last ice age and the beginning of our current climate period. This period is effectively coincident with that of our civilisation, and to emphasise this I have marked arrows indicating roughly the beginning of the Pharaonic period in Egypt (Memphis) and perhaps the oldest city in Europe (Poliochni on the island of Limnos in Greece). The temperature rise as we came out of the last ice age into that 10,000-year period of climatic stability is of the order 5 to 10 degrees centigrade. Importantly, we note that this increase is linked to an increase in carbon dioxide levels from 200 to 270 ppm.

Most importantly please note the green data points to the right of the graph. These are the measurements which represent the rise in carbon dioxide levels over the past 100 years. The current level of Carbon Dioxide is about 372 ppm. This massive and rapid rise in carbon dioxide levels is uncontroversially attributed very largely to the burning of fossil fuels to generate energy. It is unprecedented over that timescale of the earth's history which has been charted. The rate of change is also unprecedented.

Scientists are always cautious about predicting what's going to happen as a result of these dramatic changes in our atmosphere. Of course the reason is that we are dealing with an extremely complex problem. The globe and all the effects and drivers which can alter our climate, including plant and animal life, constitute a massive problem and I have to say that I admire those who are tackling it. However, massive computer programs and massive computer power are totally transforming our ability to look at complex systems, and this increases our confidence in making predictions. I am going to summarise what we know about what may lie ahead of us, but let's bear in mind that we have no previous experience of the earth in the region of carbon dioxide levels we are in now. This is unexplored territory.

It is relatively easy to extrapolate forward to obtain scenarios for future carbon dioxide levels based on different levels of fossil fuel usage – coal, oil and gas – by human populations. Such forward extrapolations were published in the IPCC Third Report last year. If for example we were to get our act together internationally, with all major players participating, we could take action to limit carbon dioxide emissions to keep below a plateau at about 550 parts per million by the year 2100. But if we continue with business-as-usual we will reach about 1,000 parts per million by 2100, which is a very substantial rise over where we are now, at 372 ppm. At each of these levels we must anticipate very substantial climatic changes.

Various independent research centres around the world have taken these carbon dioxide scenarios and, with a range of models and very large computer programs, attempted to extrapolate forward in time to see what this might mean in terms of global temperature, sea levels, rainfalls and so on. The results of their work are summarised in the IPCC 2001 report. These models are all predicting temperature rises in the region from 1.5 to 5 degrees centigrade, depending on the scenario, by the year 2100. Let me pay tribute to the work of the Hadley Centre at Bracknell in this work. The Hadley Centre is situated within the UK Met Office and the Met Office itself is in the Ministry of Defence. The Hadley Centre is regarded by many as the world-leading centre involved in this kind of work and it is interesting to ask why it managed to develop this strength. I believe it is directly connected with its being embedded in the Met Office, itself certainly amongst the two or three world leaders. The UK has historically been dependent on weather prediction capability, both for trade and for military purposes. The weather was always of great importance to us and still is. So being able to predict the weather was always an important asset and it was natural for the Met Office to be based in the MoD and it is there that it has fortunately fostered rather well. In extrapolating weather-forecasting capability forward in time, it was quite natural to extend that capability into the longer range as well. I would particularly like to pay tribute to the work of Sir John Houghton, who was Director of the Met Office for a significant period of time and also contributed seminally to the work of the IPCC.

So the question is, are these two effects, increases in atmospheric carbon dioxide level on the one hand and global average temperature increases on the other, causally linked? This is the key question. I hope to be leading you to your own conclusion. I do think it is interesting that people are still asking this question, and I think that there are some good social questions to be asked about that. Before giving this lecture I asked Alan Thorpe, previous Director of the

Hadley Centre and now at Reading University, what proof he had that human activities are involved. Of the gases that are forcing our climate up in temperature the dominant are carbon dioxide, methane and nitrogen oxide, in that order. Water vapour has a major effect on climate change, but increases in atmospheric water vapour pressure result from global warming caused by these forcing gases, yielding a positive feedback. Of course the increases in carbon dioxide levels arise largely from our need for energy. Fossil fuel burning is leading to the biggest rise in carbon dioxide, and the net loss of forests is a further important factor. Importantly, increases in carbon dioxide over the past 100 years have produced about 70% of the forcing, methane about 25%, and nitrous oxides about 3%. The increases in the level of each gas is largely derived from human-based activities, including intensive animal farming. Interestingly, there is current work on genetically engineering or breeding cows that they will produce less methane than they do now, a serious possibility that should not be discounted! Methane in the atmosphere is a much bigger forcer of climate per molecule, but there is much less methane in the upper atmosphere. Another very important point is that the lifetime of methane in the atmosphere is considerably shorter than that of carbon dioxide. If we were able to terminate, or significantly reduce, methane emissions then after a few decades it would be lost from the atmosphere. I am afraid the same is not true for carbon dioxide which has a half-life in the atmosphere measured in hundreds of years.

Returning to the Hadley Centre I now show in figure 2 a comparison between the observed average temperature changes over the period 1850 to 2000 and their model simulations based on all greenhouse gas emissions and including natural factors.

In general you would have to say that agreement is a further good indicator that we have causality here. Amongst the factors included not related to greenhouse gases are volcanic eruptions, which can have a dramatic but reversible effect on temperature, and changes in solar energy. These are all included in the model; when they take the carbon dioxide and methane forcing out, the general increase you see from left to right disappears from the calculation. This is now a very strong indicator that we are dealing with a causal relationship.

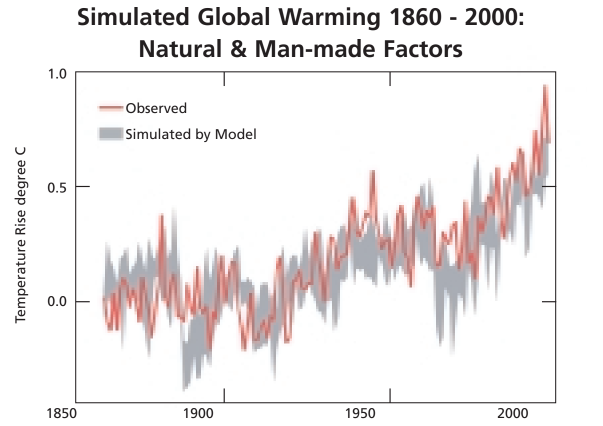


Figure 2

Source: Hadley Centre/Met Office

More approximate calculations cover the period over the next millennium. Even if carbon dioxide emissions due to human activity were very significantly reduced over the next 100 years, peaking, say, 30 years from now, carbon dioxide would continue to accumulate in the atmosphere over the next 100 to 300 years, and would then remain roughly stable for the full millennial period. This is a significant problem associated with carbon dioxide in particular.

I hope that you don't feel that I have belaboured the point but certainly in some places in the world and amongst some people, I find that this question of causality is still being discussed as if it was being approached almost de novo. I personally think that the time to call the jury in for a clear verdict has long passed.

WHAT ARE THE EFFECTS OF GLOBAL WARMING?

Should we worry about global warming? That obviously is a question that should be addressed. Wouldn't we simply have more pleasant weather in the UK? Wouldn't it be nice to have British wine amongst the great vintages and warmer summers? The answer to my question is, unfortunately, no. There is not much good about the predictable effects of global warming for any parts of the world. Sea levels will rise over at least the next 1,000 years, due to thermal expansion of the sea, and due to ice melting. We now return to the importance of ice on the globe. Warming the oceans and melting that ice which is situated on land would give rise to alarming levels of sea level rise, certainly more significant than has occurred over the last 10,000 years.

Over the period from the last ice age into our present warm era, roughly 10,000 to 8,000 BC, the sea level probably rose by about 150 to 200m. So if we now attempt to extrapolate forward over the next millennium, the large changes in carbon dioxide levels now occurring (shown in figure 1) mean that we can anticipate another dramatic alteration to our coastlines. The Hadley Centre has modelled, with the business-as-usual scenario, what will happen to the Arctic sea ice over the next 80 years. Most of it will have melted. This is already happening: last year for the first time a ship was able to sail over the North pole, a section of the oceans not previously charted. In fact it is likely that, whatever scenario we follow, the Arctic sea ice will be lost. Crossing to the West Antarctica ice shelf, there are indications of loss of ice as well, but the Antarctic has about 90% of the global ice mass and therefore the total latent heat required to melt that considerable larger ice mass means that it would take very much longer.

If we should lose all global ice, sea level rises could exceed 100m. Predictions to the end of this century are in the range of 0.5 to 1m, but due to the large masses of ice and water the process will continue into the next millennium. Even a 3m rise will lead to a significant redrawing of global maps. And because most of our large cities around the world have been positioned on coasts it would mean a very significant percentage of them would be lost to the sea.

I visited the archaeological site of Poliochni this summer on the small Greek island of Limnos in the northern Aegean. This is believed to have been the oldest European city; the excavations reveal that it originated about 6,000 years ago. The city is only about 5m above sea level, as it always has been. The shape of the island has hardly altered in all that time. In fact over the period of our civilisation most of our continents and islands have undergone little change. Of course there are places where there have been significant changes in the coastlines, but the general picture is that the map of the world that we are familiar with is one that we can happily extrapolate back over a period of about 10,000 years.

Can we do anything about this? Looking at a map of the world and extrapolating forward on the basis of what we know now, we can make some simple predictions about the number of people who will lose their homes, their cities and their infrastructure, say by 2080, following a business-as-usual consumption of fossil fuels. The numbers of people displaced, particularly from river delta areas such as at Cairo, New Orleans, and Bangladesh, but also from, for example, coastline cities and villages of India, Japan and the Philippines, would be to counted in terms of hundreds of millions. I don't want to exaggerate the effect. This will take place over a longish period of time, and so it will be a relatively gradual process. But the economic, social and political consequences generated by that number of displaced people will be simply enormous. The consequences of massive movements of people must be politically and economically destabilising on a global scale. There is an Association of Small Island States, OASIS, which is, for very good reasons, worried about their future. To take one well-known western holiday destination, what future can there be for the Maldives?

I want to include a touch of optimism in this presentation, so lets look at other scenarios. If we could stabilise carbon dioxide levels to, say, around 550ppm current models suggest that there would be a significant mitigation of the effect. In fact around the areas worst effected on the Indian and Bangladesh coastlines, the mitigation is estimated to be in the region of 80 to 90% compared with the business-as-usual scenario. Very significant improvements can therefore be expected if we could keep carbon dioxide levels down. But we must not underestimate the problems ahead of us even in that situation: there will be a substantial increase in the adverse effects we are already experiencing through increased storms and flooding around the world. We are also experiencing a serious loss of biodiversity. I am not suggesting that climate change is the only factor here, but human activity is already bringing about a large loss in biodiversity, with an accelerating loss of species and ecosystems comparable to a sixth mass extinction. The last mass extinction was 65 million years ago.

MITIGATE, ADAPT, OR IGNORE?

Now lets examine the choices that stand before us. Should we do nothing in particular, and allow market forces to work through the problems? Or actively mitigate against the production of greenhouse gases, and reduce the extent of the changes? Or adapt to the significant change that is inevitably ahead of us, managing the multiple risks that can be foreseen? We can of course choose to both mitigate and adapt to the unavoidable changes. Market forces will continue to operate, but the question is the extent to which we can rely on these and hence avoid the active mitigation choice. This is a good question.

IGNORE?

Energy supply around the world is now very largely provided through oil, gas and coal, with some reliance on nuclear and hydroelectric power. World oil production is based on finite reserves, and independent oil consultants are indicating that, at our present rate of consumption and discovery, world oil production will peak some time between 2015 and 2017. After that it will no longer meet demand, and this in itself will be a very strong economic driver to seek alternatives to oil for energy supplies. Even by 2009 50% of oil will come from the Middle East. Peter Hain, now UK Minister for Wales, has recently estimated that the net result of the military activity that Western countries – particularly the USA and the UK – might get engaged in to stabilise the Middle East region is such that it could add $1 to the cost of a gallon of petrol. And stability would not be guaranteed. Peter concludes from this that we should move hard and fast towards renewable energies as an alternative to fossil fuels and particularly to oil dependence; this would clearly also be a mitigating factor against climate change. However, it should be noted that coal and gas reserves, although again finite, would last considerably longer. There is no clear market reason to seek alternatives to replace them on a 50-year timescale.

Oil in transport is, though, a very significant portion of our energy mix: globally, about 30% of the total, including coal, nuclear, gas and renewables. I don’t think that we could contemplate moving into a future in which the private car is phased out, so we will have to seek out alternatives to petrol or other fossil-based fuels for road transport. This is where the hydrogen fuel cell could play a major role. A significant proportion of car and vehicle manufacturers are now making very substantial investments in hydrogen fuel cell technology to bring this about. General Motors, for example, is working on a "Skateboard Car" concept based on a fuel cell driven by hydrogen gas. This is a drive-by-wire car, technically very attractive: the motors and brakes are in each of the four wheels and there are no other moving parts. You can operate the car with a pc mouse. This is disruptive technology – technology which radically alters markets - at work. It is a technically attractive development, driven as much by technical adventure as by the market understanding of the vulnerability of oil supplies. The exhaust output is only water vapour, a major attraction, provided that atmospheric water vapour pressure is unaffected. We would mitigate much of the pollution of our cities. But how do we produce the hydrogen to fuel these cars without using fossil fuels? The most likely source is water, with energy from the electricity grid. Clearly this will place an even bigger demand for energy from electricity grids, potentially increasing grid demand for transport by about 30% in the long run. When will these cars be on the market? I understand that the date is coming forward in time: 2020 was a figure talked about a few years ago, but in the USA they now talk about 2010 to 2015 for fuel-cell-driven cars on the market.

MITIGATE?

Will market forces lead us onto a substitution path for energy resource, or will we have to do more than that? I can simply tell you that economic modelling does not support the notion that inaction is sufficient. Market forces alone are not going to produce the enormous switch in energy resource that is required if we are serious about a significant reduction in carbon dioxide production. So we will need to actively reduce our dependencies on fossil fuel. Our Royal Commission for Environmental Protection recommended that a 60% reduction in carbon dioxide production by 2050 would be necessary and this is matched by the Kyoto protocol established in 1997. Of course we have already made a commitment to embark on that route. One way or another though, the US must come on board a process that takes everyone in the same direction. A global problem requires a global solution. We are talking about a country with 4% of the world's population and emitting about 25% of the world’s greenhouse gases.

How do different countries compare in their per capita energy-related carbon dioxide emissions? The average Briton emits about 9 tons per year, compared to 21 tons for the average person in the USA and 1 ton in India. There is a considerable variation from one country to another, the energy mix on the electricity grids and the per capita income each playing a role. Sweden, with hydroelectricity on the grid, is down at 6 tons per person per year, and France with 87% of energy on its grid from nuclear, is also at 6 tons per person per year. Germany, which has little hydroelectricity and has 30% of nuclear power is at 10 tons per person per year, despite major efforts to increase energy efficiency. So the energy mix is an absolutely critical part of the difference from one country to another. The US Government has been particularly keen to suggest that growth of GDP is an important factor. However, even when the energy consumption is divided by GDP for each country, there is a large disparity amongst the OECD countries, the largest differences being the USA at one extreme, with Australia not far behind, and Switzerland at the other.

All countries, North and South, will need to be brought into the mitigation process. This places a particular added onus on OECD countries – on the North. We will need to engage actively in North-South capacity building in science, engineering and technology. Without that we are not going to eradicate poverty in the South, particularly in Africa, but also without that we are not going to meet the global demands of reducing carbon dioxide emissions, whilst at the same time providing much needed improvements in energy provision in the South.

In my view it is of paramount importance to achieve global agreement on a ceiling for the carbon dioxide level in the atmosphere. This will have to be a compromise between what is desirable and what is reasonably achievable. I personally believe that a target of around 550ppm is the best compromise figure, based on current calculations.

At the request of Patricia Hewitt and Lord Sainsbury, I undertook a review of energy research in the UK and one output of that review, published in 2002, was that we felt that there were six areas of research in particular where there was significant headroom between where technology is today and where it could be if more research and development were done. These included carbon sequestration, which might enable us to continue to burn fossil fuels, collecting the carbon dioxide and sequestering them safely: energy efficiency gains; hydrogen usage; nuclear; solar photovoltaics; and wave and tidal. We also urged additional funding and the establishment of a National Energy Research Centre to boost this activity. I am very happy to report that three research councils together – the Natural Enviroment Research Council, Engineering and Physical Sciences Research Council and the Economic and Social Research Council – are currently taking this forward.

I have been looking beyond nuclear fission in some detail at the question of the use of nuclear fusion as a power source for electricity grids, harnessing the energy that drives the sun. The great potential advantage, of course, is that deuterium plus tritium gives you helium plus energy and helium is non radioactive, so the ash of this energy-generating process is not a problem. The problems of radioactive waste from fission power stations are eliminated. An international project ITER is the next stage in the project towards a fusion power station. The European fusion project at Culham, the Joint European Torus (JET), has now produced all the results it was designed for: it has produced as much energy out as in. Now, I have worked through the European Union and with Japanese and Russian partners to generate a "fast track" towards a fusion power station which we can now anticipate to be some 25-35 years away. The time scale will depend on scientific and technological developments, and on the level of funding. The project will cost 4.5 to 5 billion euros over the next 10 years. In addition to the EU, Russia and Japan we are now also expecting the US to come on board and China have indicated that they have an interest in the programme.

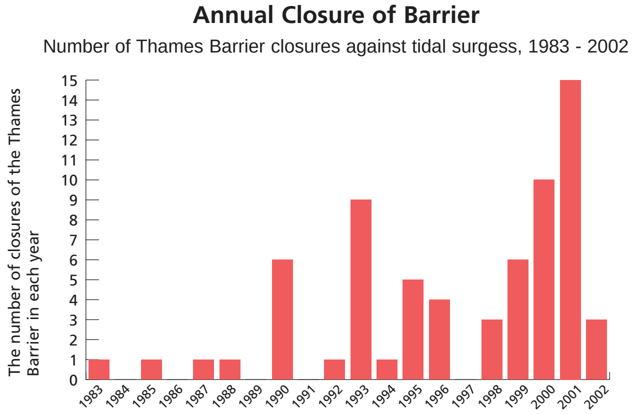
So I believe that the ITER project will proceed and will be a good way forward. But it does not provide a useful energy source for the critical phase over the next 30 years. It is worth looking briefly at the UK mix of energy on the electricity grid. To make up for the replacement of petrol by hydrogen for road transport, we must anticipate an increased demand on the grid, so any energy efficiency gains may well be offset by the demands resulting from the move to a hydrogen economy. The UK PIU suggested, earlier this year, that quite stringent renewable energy targets should be set for the year 2020: 20% on the grid, absolutely rightly. It is going to be difficult to achieve. But I think it is possible; the target should be set. Let us suppose that we achieve 20% of renewables on the grid compared with 3% at the present time. We would, despite this, be more dependent on fossil fuels than we are at the present time. This is because much of our nuclear capacity will have been decommissioned over that period. Nuclear energy on the grid will have dropped from 27% to 7%, and of that remaining 7% we import 3% from

France. The alternative scenario would be to provide market encouragement to the nuclear energy industry to replace existing plant when it comes to the end of its time. Then we would retain about 27% nuclear energy on the grid, and of course we would have reduced our dependence on fossil fuels. It is very difficult to see how we can continue to reduce fossil fuel consumption, how we can meet the Kyoto commitments to 2010 and the Kyoto Plus commitments to 2020, if we do not replace our aging nuclear power plants with the new, considerably more efficient modern plant now available

ADAPT?

1928 was the last tidal flood of great significance in London. As a result of understanding the frequency of tidal flooding up the Thames, it was decided to construct a tidal barrier, the Thames Barrier, a wonderful architectural construction. It is interesting to ask, how often has the barrier been used since it was opened in 1983? I have managed to collect that data together and show it in figure 3. It turns out that it was an exceptional act of foresight to put that barrier up, at a capital cost of 1 billion pounds and a running cost of about £100m p.a. Usage has been increasing very substantially, from less than once a year in the first 5 years to more than 6 times a year, on average, over the past 6 years. This is a clear measure of increased storm levels on our coastlines. It is estimated that just one flood breaking through the barrier today would cost about 30 billion pounds in damage to London. We are looking at a very substantial return on the investment, but the return is in terms of what didn't happen. That is always the great difficulty here; what's been saved everyone takes for granted.

Within the Office of Science and Technology we have a Foresight Programme, and within that Programme I have initiated a project, tying in very closely with Department for Enviroment, Food and Rural Affairs, on Flooding and Coastal Defences. The idea of the foresight programme is that a team are set to work with experts, drawn nationally and internationally, to look over the next 20 years at what threats there are to the UK from floods and lack of coastal defences, particularly taking global warming into account. At the present time, due to the increased storm and flooding activity we are currently experiencing, something like 10% of our housing is in flood plains. This constitutes a very significant problem with insurance and personal, corporate and economic losses, so the question is, how can we adapt to what is inevitable. The team will report back in about a year from now, with recommendations for government on actions to be taken, including engineering projects. There are enormous difficulties in this programme because extrapolating forward to make predictions on climate change, as I hope I have indicated, is not an easy game.


Annual Closure of Barrier

Number of Thames Barrier closures against tidal surgess, 1983 - 2002

Figure 3

Source: Enviromental Agency

IN CONCLUSION

Now I will move back to the international scene to address the question of what it would cost to keep global carbon dioxide levels below 550 ppm. An attempt was made to estimate this by the IPCC and published in their Synthesis Report last year. They estimate the global costs to be in trillions of 1990 US dollars. But what is very important is that these estimates do not account for the savings associated with the damages and losses avoided by taking this action – and the global economic and political destabilisation that could ensue.

I will end with a simple comment. If we put all of our effort into oil recovery for energy production without carbon dioxide sequestration and continue to burn gas and coal, instead of seeking to replace fossil fuels, it is very likely that carbon dioxide levels in the atmosphere will exceed 750 ppm. This will in all likelihood lead to a second irreversible effect; the eventual loss of global ice, and hence also of our coastal cities and dwelling places as sea levels rise. When I say eventual, I am talking on a long-term scale and nobody can say what the length of the time scale is: it may be 1,000 or it may be 10,000 years: it may even be a shorter period than that. The period leading up to that point is likely to be one of substantial economic and political change.

I began with the ice cap of Kilimanjaro. The picture is much the same for most tropical and mid latitude glaciers: it has recently been estimated that the altitude below which glaciers generally lose mass has risen by about 200m world-wide in the last 40 years. Most mountaineers are fully aware of the movement upwards of the edge of the glaciers. What is happening is on a global scale. It is an important corroborative measure of the extent of global warming that is currently under way.

LINKS

British Antarctic Survey: www.antarctica.ac.uk

Department of Meteorology, University of Reading: www.met.rdg.ac.uk

The Energy Review - Performance and Innovation Unit Report:
www.cabinet-office.gov.uk/innovation/2002/energy/report/

Hadley Centre, Met. Office: www.met-office.gov.uk/research/hadleycentre/

Intergovernmental Panel on Climate Change (IPCC): www.ipcc.ch

Tyndall Centre: www.tyndall.ac.uk

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