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Department of the Environment

CLIMATE WARMING

SPEECH TO ROYAL INSTITUTE

INTERNATIONAL AFFAIRS

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CLIMATE WARMING

1.1 **Aims**

My aim this afternoon is to explain in some detail the scientific case that underlies the Government's concern on global climate change. The UK Government is one of the few to have advanced a strategy on climate change. You will find it contained in the Appendix to Dr Everest's report which is published today. This strategy also appears in the Government's response to the World Commission on the Environment, the Brundtland Report. These constitute my texts for this presentation.

1.2 **Climate and Weather**

It will help if at the very outset I differentiate between weather and climate. 'Weather' I take to be the instantaneous state of the atmosphere - the data for example displayed in the window of the London Weather Centre in Holborn. It is the data which effect our immediate decisions to use the capital equipment we have to hand - whether to put up an umbrella or the sunshade. 'Climate' in contrast I take to be a statistical measure of these weather variables over some defined period. Climate is the general view which we use for our long term decisions such as capital formation. For example, we use statistics which have been accumulated over many years as an aid to deciding on the size of the heating system we should install. Long term statistical measures also correlate with the survival and growth of the living natural world, with its water resources and with the weathering of rocks and the condition of soils.

1.3 Determinants of Climate

For climate related decisions, we are seldom interested in geographical averages of climate measures, but we frequently have to live with them as the best available data. Thus of course we all know that gardens can have frost hollows or housing estates exposed corners, but these are not details we can reasonably expect to be retained in regional statistics. Yet even beyond these micro climate variations, the regional climates of the Earth change markedly from region to region. Both the absolute climate and the regional differences can, in the end, be traced to differences in the incident solar energy. The sun can be thought of as the powerhouse driving the climate. Climate change in turn can similarly be traced to changes in the incidence of solar energy, possibly modified by the atmosphere or the oceans. Finally though, climates are classified into regions they are interdependent. The Gulf Stream climate of Cornwall takes that characteristic because of atmospheric and oceanic processes that begin in the north Pacific Ocean. A particularly stunning example of interdependence is to be found in modern forecasting. The Met Office can now forecast with some accuracy the Sahel weather some 6 months ahead on the basis of global sea temperatures. The recent tragic floods may have in part been associated with an air pressure event that began in the Pacific. No five-day prediction of today's weather can be made without a global model of the atmosphere.

1.4 Past Climates

Using some of the most recent advances in paleoclimatology, the frequency of past climate fluctuations can be analysed. For example, Nick Shackleton and his team at Cambridge have found the climate over the last 200,000 years well accounted for by periodicities in the earth's orbit at 23,000 year and 41,000 year. We are currently towards the end of a warm interglacial period. Some estimates put the onset of the next ice age at some 1,500 years hence. DOE more cautiously put the figure at 5,000. As Sir Crispin Tickell has remarked in his excellent little book 'World Climate' this is certainly outside most policy frameworks. It is certainly outside my scope today. However, it is sobering to note, on the scale of man's intellectual rather than technical development, that the next ice age is apparently nearer to us in time than the founding of Judaism or perhaps even the founding of Christianity.

1.5 UK Policy

My scope today is also of a much shorter timescale - but one that is nevertheless longer than many of the discussions in the Institute - it is the real possibility that over the next 50-100 years discernible changes in key climatic variables may be attributed not to the whim of nature, but to anthropogenic activity. The Institute is publishing its own analysis of this situation today. It was most recently discussed at an International Conference in Toronto, the conclusions of which are reproduced in the RIIA report. You will also find there the message that Lord Caithness sent to the Conference which explains UK policy. The key points stated there and in the Brundtland response are:

1. Man's activities can effect climate, although in the medium term we have much difficulty in assessing the magnitude and significance of the effects.

2. Man-made climate change could be the single greatest challenge to the principle of sustainable development.

3. Over the next thirty years our understanding of the issues will progressively improve. The development of policy must pace the development of our understanding.

4. The immediate and optimum policy is

   i. the wide ratification and strengthening of Montreal protocol on CFCs;

   ii. proper economic pricing of fuels on the world market;

   iii. improved energy efficiency worldwide;

   iv. better land use practices at the global scale;

   v. international effort to resolve major scientific uncertainties before the end of next decade.

To begin my exploration of the reasoning underlying these principles may I first introduce you to the greenhouse gases and their effects.

2. Greenhouse Gases

2.1 Time series of some atmospheric gas concentrations taken over the last 30 years show a distinct upward path for some gases. If we go back to the analysis of air trapped in ice cores we have an even more dramatic picture of rising concentrations since the industrial revolution. The concentrations are very small. The significance is that these gases have molecules that are actively absorbing and emitting strongly in the infra-red spectrum. It is the analogy with a related property of glass that has given the name greenhouse gases. If the processes are a little more complicated than those that keep a greenhouse warm the term is still a much better fit than acid rain is to air pollution and I propose to keep with it. Like greenhouse glass, the gases are transparent to the majority of solar energy but are reasonably opaque to the infra-red radiation at which the Earth's surface would lose heat to reach thermal equilibrium. As we have seen modifying the radiation balance must lead to some change in climate variables.

Carbon dioxide is the most familiar greenhouse gas. Water vapour is also a very important greenhouse gas. Other relevant gases are methane, nitrous oxide, ozone and CFC's. It is perhaps worth establishing clearly that although the details of the computation are not easy, the qualitative implication that there will be a change is clear, and is unchallenged. This change may induce effects on the climate such as changes in cloud cover so that some climate variables remain unchanged but formally such induced feedback is also a climate change. The question is not whether the accumulation of these gases has changed the climate, but whether the change is, or is likely to be, significant.

2.2 Origin of Greenhouse Gases

It might also be questioned whether these increases in greenhouse gases are man-made. For CFC's the case for anthropogenic attribution is trivial. The major contaminants CFC 12 and CFC 11 have no natural source. We can also make some progress in tracking down the origin of the carbon dioxide (CO_2). Atmospheric (CO_2) is enriched with carbon isotope 14 by the action of cosmic rays. This isotope has a half life for decay of some 5600 years. Proportionate depletion of C14 as atmospheric carbon levels increase is an indicator of old carbon - ie fossil fuel carbon - entering the atmosphere. Man's emissions from fossil fuels and the observed increases in atmospheric carbon are only a small fraction of the massive quantity of carbon that moves backward and forward between the atmosphere, oceans and the land. However fossil fuel emissions alone are more than enough to account for the observed rise.

Estimates suggest that deforestation by releasing the living stores of carbon to the atmosphere has also contributed to the overall increase.

The characteristic of most greenhouse gases is a tendency to accumulate in the atmosphere. Atmospheric carbon might take 500 years before it is taken out of the biosphere carbon cycle. CFC12 has a lifetime of over 100 years. The emissions of these gases thus leads to a quasi-irreversible accumulation.

This leads us to the first principle which a century ago would have seemed hardly conceivable, that the scale of Man's activities can effect climate.

3. Estimating the Climate Change

3.1 Estimate of Carbon Dioxide Concentrations

Let me now turn to the calculation of the effect on climate of increased concentrations of greenhouse gases. The first point to note is that molecule for molecule there is a wide difference in effect. In regions of the spectrum where much absorption is already taking place, an extra molecule is far less effective than in a region of the spectrum where there is currently little absorption. This is why a single molecule of a CFC is some 10,000 times more effective than a molecule of carbon dioxide. It has therefore become customary in discussing the total greenhouse gas effect to talk of effective carbon dioxide concentrations, although this may place carbon dioxide in an over prominent position. In fact, some forecasts credit carbon dioxide with under half of the greenhouse warming effect by the middle of the next century. The emerging role of these other gases is one reason why estimates of warming have advanced since the reviews of the late 1970's.

The calculation involves estimating by how much the earth's surface needs to warm up the atmosphere so that the rate of heat loss back to space accounts for the total solar energy incident on the earth's surface. The steps in the calculation for an hypothetical atmosphere which has come to thermal equilibrium with twice the pre-industrial effective CO_2 concentration is particularly informative.

The straightforward calculation suggests that a rise of about $1^{o}C$ would follow from the CO_2 doubling alone. However that rise in temperature would somewhat reduce the extent of ice cover and so expose more of the earth to warming. What is more, as the oceans and air warm up, water evaporation increases as does the ability of the air to hold water vapour without saturating. Water vapour, as we have seen, is a very important greenhouse gas and so further warming follows. Finally, and possibly the most difficult feedback to incorporate, is the effect of clouds. High cloud adds to the greenhouse effect but low cloud has a negative effect acting as a reflector of incoming radiation. We would need also to allow for the optical transmission properties of the new cloud formations.

3.2 Climate Feedback is large

The disturbing aspect of these induced effects are that they are larger than the original greenhouse effect by say a factor of 2-3. We can either use idealised models of these processes relying on the overall energy balance to generate our answers, or employ full 'General Circulation Models' (GCM's). In the UK, John Mitchell's team has been using one of the world's most advanced models at the Met Office. However, modellers would be the first to admit that serious simplifications are present in even the most complex models. Fine structure on the scale of clouds cannot be directly modelled but has to be assessed by approximations. Possibly most serious is that the coupling of the dynamics of atmospheric circulation to an ocean circulation is at present in early stages of development.

3.3 Climate Models

It is for this reason that modellers have been reluctant to attach much significance to the regional differences in climate implicit within the global circulation calculation or to the estimates of precipitation. The four or so GCM's in operation do not agree at this level of detail, although some general characteristics are found in most calculations; the equilibrium warming after a doubling of CO_2 has occurred is predicted to be between 1.5 and 4.5^{o}C above pre-industrial levels, encompassing the range of simple energy models (lower end) and the GCMs (upper end). There is less consensus as regards rainfall. On the whole, the hydrological cycle is speeded up with global rainfall increasing by some 10%. Regionally, there is considerable variation, but one fairly constant feature is increased drying up of the soil in mid-latitudes in summer. The modelling approach can give little guidance on the frequency of rare events. Knowing how the average temperature changes does not give us much insight into the nature of extreme cold or hot spells - knowing that the total prize money in a lottery has increased does not guarantee that the 'star prize' is any bigger.

3.4 How do the models predict 1988?

With such a range of uncertainty it might be thought a possibility to test the models against the climate record for at least global average temperature. It is by no means an easy task to reconstruct the past global average temperature. Tom Wigley's group at the University of East Anglia, and Chris Folland at the Met Office are among the world leaders in this field. The current temperatures compared with 1860 are rather lower by about 0.6-0.8^{o}C than we would expect from a climate at equilibrium with the current levels of CO_2. However as Jim Hansen of the Goddard Space Laboratory has pointed out most of the feedback mechanisms which amplify climate change take time to develop as the surface temperature rises. Therefore, the indication of greenhouse gas warming in its early decades is expected to be rather lower than equilibrium models suggest. The most that can be said is that the observed rates of rise of temperature since 1860 are consistent with the current state of the art model, albeit with the models somewhat over-estimating the effect.

This leaves us in a rather unsatisfactory situation. The climate variable about which we have most confidence, the global average temperature, is not very useful for determining effects at any given locality, nor can we be certain of its timing. The more important climate variables such as regional temperature values, or precipitation, or the frequency of extreme events are presently unknown or unreliable.

However the situation will not always remain so uncertain, At a brave guess, climate models will be of sufficient reliability, say 30 years from now, for their use in determining how we invest in projects with a climatic component such as sea defences or construction or new crop development. The question then is not whether the present concentrations of greenhouse gases are a cause for concern but whether future levels might be. This is critical to the second conclusion of UK policy that man-made climate change could be a challenge to future sustainable development.

4 Future Greenhouse Gas Concentrations

4.1 Energy Scenarios

To calculate future greenhouse gas concentrations we need to compute both the rates of emission and the percentage of emissions that remain in the atmosphere. The second problem involves some technical uncertainties, concerned with the behaviour of the biosphere, especially the oceans. Our knowledge is far from complete, but it is at least amenable to research methods. However, the first calculation involves a quite different kind of uncertainty, since it is asking us to predict largely what we and subsequent generations are likely to choose to do.

The Government has argued on many other occasions that energy forecasts are notoriously difficult to make and notoriously unreliable. Energy forecasts over the period I am envisaging are then at best heroic. I would in any case like to establish the next point without appearing to make too much reliance on the black art of energy forecasting.

4.2 Population and Energy

Rather than pretend that I can predict future consumption, I will look at a prescriptive goal that the international community has set itself for the end of the next century as a step towards ensuring a sustainable future. I will then try to estimate the level of greenhouse gas emissions that a business as usual approach towards that goal might imply. In essence, I am testing the goal for the sustainability of its consequent impact on climate.

The present world population is about 5 billion with a per capita rate of primary energy consumption of about 2KW. Currently, fertility outstrips mortality, so that the population is rising. Even when family planning programmes have brought the two rates to equality, the population continues to grow for a while until the age balance is obtained. The UN has put a target of 10 billion by the end of the next century for a stable age balanced world population. Most commentators, assuming a disaster free 21st century, would not put that target as a high figure. I am not competent to judge its realism, but it is a useful marker. As the Brundtland report points out, we cannot expect that stabilisation of population to be without resource consequences. For example, European populations have reached stability with a level of prosperity that incurs a primary energy consumption of 5-6 KW per capita. Adopting this figure as the per capita consumption for the target population at the end of the next century is then an internally consistent 'business as usual' scenario. This would lead to an end of 21st century consumption of 55TW, or an average growth rate of about 1.5% - rather lower than the historical trend. It gives 20TW energy consumption in the 2030's which is pretty 'middle of the pack' amongst energy projections. I emphasise that this is a scenario in the strict sense and not a forecast.

If the 55TW at the end of the next century were met with largely the current world mix of fuels, then between now and the stable population we would have discharged into the atmosphere somewhat under 1500Gt of carbon. If anything, this is an under-estimate. About half of this might be lost from the atmosphere, principally to the seas, leaving just under 400ppm extra CO_2 in the atmosphere. Given that the pre-industrial level was 275 ppm and the current level 350ppm, this leads closer to a tripling of pre-industrial CO_2. At the average growth of 1.5% doubling of CO_2 above pre-industrial levels occurs about mid-way next century.

This conclusion is arrived at without taking account of the accumulation of CFC's or other greenhouse gases. It demonstrates that in setting some of our international long term goals we will need to check them for climate sustainability.

5 Climate Induced Changes

5.1 Doubling CO_2

To reach the second conclusion of UK Government policy - that climate change could possibly represent the largest challenge to sustainable development, I need to look more closely at the possible climate in the middle of the next century. Unfortunately, few of the calculations have traced the evolution of future climate with time. However, for my purposes I can use the results of the models that estimate the climate with an atmospheric CO_2 concentration that has remained constant at double pre-industrial values long enough for equilibrium to be established.

As I mentioned earlier, the predictions for 2 X CO_2 are for an equilibrium range 1.5-4.5^{o}C above a pre-industrial level some 0.5^{o}C lower than today. If these figures seem small compared with weather variations, they are significant in annual average temperature terms. As a guide for mid-northern latitudes we find that moving north 150-300km or so is equivalent to a drop of about 1^{o}C. Thus some 4^{o}C separate the annual average temperatures of the Hebrides and the Scillies and SW France. We can conclude that equilibrium warming is thus significant in terms of both natural ecosystems and human societies. To go much further requires detailed climate impact studies.

5.2 Climate Impact Studies

There are a large number of climate impact studies that are now being undertaken throughout the world. Martin Parry of the University of Birmingham has made a particularly conspicuous contribution to the recent development of methodology in this area. Necessarily, such studies have to make some heroic subsidiary assumptions; given that estimates of even the long term equilibrium regional forecasts are unreliable, and there is no clear guidance on the scale and frequency of rare events. A particular complication is that soils and water tables can take many years to come into equilibrium with climate change. Most studies have taken the form of providing climate scenarios. For example some recent desk studies commissioned by the DOE on climate change was envisaged of about $3^{o}C$, with winters and summers (particularly the former) both warmer. Northern England and Scotland would become more temperate but possibly wetter. The climate of the South of England would approach the maritime climate of SW France.

Possibly the most vulnerable systems revealed by these studies are natural ecosystems that for some reason are restricted in their opportunity to migrate. Here the stress is most strongly felt through relative rather than absolute changes in climate. Thus, even small changes in precipitation in the world's semi-arid regions are far more critical than large changes in temperature. By an analagous argument, the expected northerly advance of the Boreal forests, reflects temperature rather than precipitation change. Any natural ecosystem unable to undertake the poleward advance is then at risk from climate warming. It is also clear, that the rate of climate change is critical for some species, such as trees where propagation rates even under ideal conditions have been estimated to lead to an advance of less than 500 metres a year.

In contrast, managed land uses tend to have much greater opportunities for response particularly when, as in my example scenario, steady economic growth is taking place. Although sometimes framed in these terms, it seems unlikely that climate change from these effects can be envisaged as forming a profit and loss account. There remains, however, one effect of climate warming which although beset with considerable problems of estimation is accepted as offering only a negative effect - sea level rise.

5.3 Sea Level Rise

Sea level rises result from climate warming through two principal mechanisms. Firstly, as the seas warm they expand. As mentioned earlier sea warming will also be associated with a reduction in ice floes. However since these displace their own weight in water, ice melting does not contribute to the increase in volume. Secondly landed ice, can provide melt waters.

It is estimated that perhaps about one third of the historic rise has been due to melting of glaciers. Recent calculations by Wigley and Raper have given a value of 10cm/OC realised warming for thermal expansion alone. However, there is a bias in the sea level datasets to the Northern Hemisphere and there are few data on trends in deep sea temperatures. There is further uncertainty on the future mass of land ice, since, although warming would tend to reduce the volume, increased precipitation, Mostly in the form of snow would have the opposite effect.

If, of course, climate extremes were to continue, and say the West Antarctic ice sheet were to move, the volume of water involved would be immense, possibly a sea level rise of 5m. However, this is likely to be a prospect that would be more for the citizens of the 21st Century to consider than ourselves. For some countries even the prospect of a 40cm rise is daunting. In the UK the greatest impact of such a rise in sea level would be on soft coasts protected by sea walls. For example an 80cm rise on the Essex Coast could lead to the present upper marsh being lost to reversion to lower marsh with a 20% reduction in area of mud flat.

With sea level, as with natural ecosystems, the rate of rise is important to the extent to which it can be accommodated by economic development. Sea defences, are of course designed to protect against extremes, where unusual wind events play their part. Current modelling techniques gives us little assistance in this regard.

5.4 Sustainability

These examples are enough to demonstrate that the man-made climate change consistent with my example scenario is significant in its impact on both natural resources and the managed environment, and could indeed represent as Lord Caithness' statement says, the largest single challenge to sustainable development'.

I would now like to turn to the policy response of the UK Government.

6 Setting Climate Objectives

6.1 Designing a Policy Response

In determining the optimal policy response it is essential to recognise that the oxidation of CO_2 with the release of energy is part of the reason for burning fossil fuels. This contrasts with say the sulphur dioxide emissions from coal which are evidence of only a tiresome contaminant. If it were possible, the optimal strategy to fulfil the scenario I described earlier would be to gain as much economic benefit from burning fossil fuels until the tolerable limit of climatic change was reached, and then just 'turn off' the tap. This is not practicable, at least in a 'business as usual strategy', and it would clearly be necessary to reduce fossil fuel consumption ahead of breaching any hypothetical climate quality objective. Nevertheless the point remains that an appropriately applied 'mid-term' correction as Irving Mintzer has described it is the optimal policy. It may of course be that if a mid-term correction is required at all, it would occur more than 30 years from now, and therefore have the benefit of climate models virtually free of current uncertainties. But as we shall see with the present range of feedback factors we cannot be absolutely sure that we have 30 years before a mid-term correction might be necessary.

What is essential to avoid on my example scenario is unnecessarily slowing world economic growth. If that did occur, the goal of stabilising world population through greater prosperity in the poorest nations is placed in jeopardy. As recognised by the Brundtland report, the world economy as well as the climate is global. To move from these general principles, to the action identified by the UK Government as necessary now, it is helpful to look more closely at possible climate objectives.

It is not surprising, in the current uncertainties, that the search for criteria by which to judge the tolerability of climate change has been rather desperate. One formalism which originated with work of the World Resources Institute is to look to warming commitment. Since most greenhouse gases have lifetimes in the atmosphere of 100 years or more, they effectively represent warming commitment inherited by some future generations. For the analyst this approach has the advantage that it sidesteps the issue of the lag in thermal response to greenhouse gases.

The commitment argument, possibly, has most force as an objective, when linked to some of the intrinsic uncertainties in our models. Thus, for example there is doubt whether our models could give the right answer for climate warmings much above 10^{o}C where the temperature profile in the lower atmosphere would be increasingly hypothetical. A commitment above this level would essentially leave future generations flying blind. Possibly, the most onerous criterion would be to limit global warming to close to the peaks of the last inter glacial maximum. Over this threshold we have no palaeoclimatological record against which to cross check our models. That threshold is only some 1^{o}C away. Future generations if not flying blind would be increasingly flying on their own as the warming approaches say 2^{o}-3^{o}C above 1980 levels. Both these criteria only have force whilst we are still perfecting our modelling techniques. Warming commitment has less force as a criterion when applied to the effects of climate change. Climate impact studies based on the steady state have tended to cluster in the region of 3^{o}-4^{o}C above present levels. However the rate of change in temperature is likely to be just as critical. As climate models improve it might be possible to further sharpen these criteria. Thus precipitation is a vital climate variable in some contexts, but presently has not emerged in any discussions as defining a possible tolerable climate change.

6.2 Warming Commitment

To illustrate the strategy implications of a warming commitment criterion on the example scenario, I will need to perform some climate warming calculations. For this purpose I am going to use some formulae developed by WRI for their own analysis of this problem. They are rather crude, but since I am keen not to make climate warming calculations appear a 'black art', they have a special attraction. I emphasise however that it is the qualitative conclusion to which importance needs to be attached.

According to the WRI formula for every percentage point increase in CO_2 concentration the warming commitment increases by 0.07°C-0.15°C. Figure 1 gives an illustrative plot of this calculation for my sample scenario, which the smallest home computer or pocket calculator could manage. Note the characteristic slowing in the rate of rise despite the increasing growth in CO_2 as the lower atmosphere becomes opaque to infrared radiation. With the lowest estimate of feedback, the world might need to include climate change in some of its capital projects towards the end of the next century, but it would be able to do that with the benefit of climate models largely completed by the beginning of that century. On the example scenario, it would also be a relatively prosperous world with the benefit of a stabilised population. In contrast, using the largest feedbacks currently discussed there would be much less than one or two decades left to resolve key uncertainties.

However, I would take issue with Dr Everest that this leads to a wait and see strategy. The UK Government's position is quite the reverse and states a number of actions which need to be put in place now by the international community on the basis of the current evidence, and in preparation for any future possible mid-term correction.

1%

6.3 Producing CO_2 Inefficiently

The Government has identified areas where economic inefficiencies have distorted the world economy to produce more CO_2 for less growth. The key distortion is energy pricing. The Institute will be well aware of all the shadow discounts that have been applied from time to time in parts of the world energy market, in the interests of some other policy objective. The consequence, of course, is that more fossil fuel is burnt than is economically justified. The UK response to the Brundtland Report emphasised the importance of correct energy pricing. This includes, of course, proper application of the polluter pays principle for environmental costs. It also follows that those countries which have withdrawn from nuclear power for non-economic reasons will need to review their policies. Proper energy pricing then supports both economic development of renewable energy resources and greater investment in energy efficiency.

These are policies which, are of course, justified now in their own right. Clearly with the prospect of climate change they need to be taken more seriously. If policies which are in any case justified, which also ameliorate climate change, cannot be undertaken by the international community then the outlook must be grim if more direct action were ever to be needed.

6.4 Percentage Reductions

The draft Toronto Conference Statement, which appears in Dr Everest's book proposed a 20% reduction in CO_2 emissions from developed nations by 2005. In many ways that would have been a disappointing recommendation. By using the formalism tried with limited success for regional pollution issues in the early 1980's it fails to recognise the global aspect of greenhouse gases. As far as climate warming is concerned, it does not matter where the steel used by an economy was forged. The CO_2 emissions will be very much the same. If capping developed countries emissions simply involves exporting those emissions elsewhere nothing will have been achieved. The final text of the Conference statement that emerged last week looks for a 20% global reduction by 2005, but regrettably still makes little reference to the long term sustainability of that strategy.

6.5 **Deforestation**

Land use practices have also been a major source of CO_2. In the past, they were the main contributor, and they still contribute some 20% of emissions. In the long term, of course, forests cannot be cleared forever and fossil fuel emissions remain the dominant source of CO_2 at the end of the next century. However, good land management does not necessarily involve the substantial loss of carbon to the atmosphere, and is again justified in its own right. It, therefore, also plays a part in the immediate strategy, and may have a further contribution to the biosphere's control of the carbon cycle of which we have only the most limited understanding.

6.6 **Including Trace Gases**

We have also seen that other trace gases have been recognised as important greenhouse gases soon after Berrill reported in 1981. It is, therefore, essential to add to my calculation the effect of these other gases. Considering the effort that has been devoted to energy forecasts, the projections of other trace gases are relatively crude. It is not, for example, self-evident what are the future emissions of methane that are consistent with my example scenario. Let me then begin by taking 1985 atmosphere concentration growth rates and assume that they are maintained over the next century.

Considering how small the concentrations are involved the results are quite remarkable using the WRI formulae, especially for the two chlorofluorcarbons (Fig 2). This is perhaps not too surprising because CFC's are radiatively active in a region of the long wave spectrum where CO_2 has little effect. If these growth rates had come to fruition, then the deduction of the earlier strategy is completely undermined. Although nobody was foolish enough to use such extreme growth rates in the early 1980's, difficulties in estimating CFC concentrations led to some wide variations in the so-called effective CO_2 concentrations that have been quoted. If I modify the model to the position before the Montreal Protocol with a limit to emissions averaging at about 1000 kilo tonnes per annum then I obtain a scenario that is at least not catastrophic.

Of course, concern about CFCs has principally focussed on their effect on the stratospheric ozone layer. The Montreal protocol if ratified by all producer nations will make a significant step towards not only protecting the ozone layer, but also reducing future greenhouse warming commitment particularly in the medium term. This additional benefit was recognised in the Stratospheric Ozone Review Group report. <u>But</u> it is worth noting that many of the newly industrialised nations which contribute significantly to the scenario's growth in CO_2 have yet to become signatories. This clearly leads to the very first of the Government's policy principles which is to ensure the widest ratification of the Montreal protocol. If that cannot be achieved then the prospects for the future global conventions on the atmosphere must look gloomy.

Unilateral action by the developed world on this scenario would only be of short term benefit. New CFC's tend to have much shorter lifetimes that CF11 and CF12 and generally lower greenhouse effects. The objective identified by the recent SORG report of stabilising stratospheric chlorine concentrations is thus likely to lead to a parallel stabilising or even improvement of CFC greenhouse gas contributions. The Government has already indicated its intention to press for the necessary reductions. The other trace gases, have, as I have said a rather uncertain forward projection. They are by no means insignificant in their effect if large positive climate feedbacks do prove to be present, and further research is required to track down their precise origins.

6.7 Rate of Temperature Rise

Before concluding, I should also like to look briefly at the policy response that follows from a climate criterion based on a rate of temperature rise. This is a far more attractive criterion than warming commitment, because it enables us to relate the criteria both to effects and to a tolerable degree of adaption. It will be one of the most important outputs of climate impact studies. To date, few criteria have been proposed. The UNEP-WMO Conference at Bellaggio identified $0.1^{o}C$/decade as a 'safe' figure. It reflects the sort of rise the world economy at the beginning of this century took in its stride. However, in other respects it may be too extreme since its key criteria were forests in relatively dry areas and a sea level rate of rise rather higher than now thought realistic. We need in any case to improve our climate modelling so that the dynamics of thermal lags of the oceans can be properly incorporated.

Similar conclusions must apply to immediate action. Firstly, we need to use models to guide policy. Even if the oceans slow the response, the warming that has been banked up in the atmosphere cannot be quickly reversed. We can only confirm a rate of temperature rise several decades after its onset because of random components of climate. Secondly, with the least onerous of climate feedbacks the international community could respond safely after climate models were perfected. If the more extreme feedbacks were imposed, there would be relatively little time - albeit measured in decades - to respond. Again, a high priority for placing an early higher limit on the scale of feedback emerges.

7. Conclusions

This outlines the rationale behind the UK Government position. Changes in greenhouse gas concentrations will alter the climate. The international community is already setting itself targets for sustainable development that involve rates of greenhouse gas emission doubling the effective CO_2 sometime next century. The effects of this emission could present a threat to sustainable development. Ideally we would like to be able to wait until our climate models have been perfected. This strategy is plausible for the lower bounds of confidence existing models. However, we cannot exclude the possibility of much stronger climate feedbacks being present. The Government has made it clear that it believes it important to set in hand policies already justified which would put us in a better position if further action were to prove necessary. Of these the wide ratification and strengthening of the Montreal protocol is vital. However other strategic elements are also important.

Energy pricing must be economic and not disguise hidden subsidies which 'over encourage' fossil use and dissuade against energy efficiency or penalise economic exploitation of renewable energy. Those nations who would wish to reject nuclear power for non-economic reasons will need to review their policy. There needs to be wide dissemination of economically viable techniques for the efficient use of energy. Justified in its own right, proper land management practices on a global scale are also helpful in limiting the growth of CO_2 emissions.

Finally our scientific understanding of man's effect on climate needs to be advanced with some urgency. Some immediate research priorities emerge which are needed to guide the international community over the next few years, particularly on the scale of feedbacks to the global average temperature. This is not research that can be carried out by any one nation alone. As you will have gathered from my presentation, UK scientists are playing a leading role in current developments but in view of how tight our timetable may become the effort must be international.

For the longer term one aspect of this problem stands out starkly. The extent to which greenhouse gases accumulate in the atmosphere depends on the ability of the oceans to accept them. The rate at which the earth responds to greenhouse gas forcing depends on the rate at which the oceans warm through circulation and diffusion processes. The regional patterns of climate will not be fully resolved until our understanding of ocean circulation and mixing matches our understanding of the circulation of the atmosphere. In all, if the sustainability of economic development is in question, then as Fred Koomanoff, the manager of the US CO_2 programme recently said 'the answer lies with the oceans'.