THE GREENHOUSE EFFECT: GLOBAL AND AUSTRALIAN PERSPECTIVE*

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The planet Earth has a mean surface temperature of 15°C, about 30°C above the temperature that would exist if there were no infrared-absorbing gases, greenhouse gases, in the atmosphere. These gases include water vapour, carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). The global activities of Man are changing the concentrations of these naturally existing gases and adding additional greenhouse gases which are entirely Man-made. Since the middle of the last century, CO_2 concentrations have risen by 25%, CH_4 by 110% and N_2O by 8%. The Man-made chlorofluorocarbon gases were non-existant in the atmosphere prior to the 1930s.

Undoubtedly, this will change the temperature of the planetary surface. The degree of warming will depend on just how much more of these gases we release into the atmosphere, how long they stay airborne and the sensitivity of the atmosphere to each gas. This paper reviews the evidence that suggests that by the year 2030, the combined effect of all of these gases will be equivalent to a doubling of the concentration of CO_2 and that this is expected to warm the lower atmosphere by several degrees.

Because the warming is not expected to be even throughout the atmosphere, atmospheric scientists anticipate that there will be subtle, yet important changes to the way the global atmosphere mixes, leading to changes in rainfall patterns, storminess, frequency of extreme events, etc. While there is general agreement as to the nature of the global warming on average, the regional and seasonal climatic impacts are very uncertain. Some discussion is given concerning the research underway to improve the regional predictability, and the need to use climate-change scenarios to assess the sensitivity of regional hydrology and water use, agriculture, natural environment and societal responses to climate changes. The paper includes some discussion of preliminary estimates of the sensitivity of Australia to such changes. Such assessments are important in deciding to what extent considerations need to be given to planning for adaptation or avoidance of the effects.

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The global and Australian budgets of greenhouse gas emissions are presented as background to consideration of possible emission control strategies.

INTRODUCTION

There is now a strong consensus amongst atmospheric scientists that global warming during the next few decades is highly probable as a result of the accumulation of greenhouse gases in the global atmosphere (DOE, 1985 a-e; Bolin *et al.*, 1986; WMO,1986). These gases are generally long enough lived in the atmosphere that it doesn't matter where they are released, they soon become widely dispersed in the atmosphere and influence climate globally.

Without the presence of water vapour and carbon dioxide (CO_2) in the atmosphere, the earth's surface temperature would be 33°C lower than it is today. For many years the process of retaining heat in the lower atmosphere has been known as the greenhouse effect, and CO_2 as one of the key agents which causes this effect, has been known as a greenhouse gas.

Greenhouse gases such as CO_2 and water vapour bring about the greenhouse effect through the property that they absorb strongly in the infrared region of the electromagnetic spectrum. Sunlight, the source of energy for the earth-atmosphere system, is principally in the visible region, where the earth's atmosphere is almost transparent. Of the total amount of incoming radiation 31% is reflected by clouds (21%), by particles in the atmosphere (6%) and by the earth's surface (4%), while the other 69% is absorbed by ozone in the stratosphere (3%), by water vapour, clouds and aerosols in the troposphere (18%), and by the earth's surface (48%).

To maintain total energy balance, long-wave radiation, equivalent to the 69% incoming short-wave radiation which was absorbed, needs to be emitted to space. The bulk of this energy comes from the earth's surface which emits black-body radiation (at about 300 K this is infrared radiation). Greenhouse gases and clouds can intercept this radiation, and re-emit it in all directions, thus redirecting a significant amount back down to earth. As a result of these processes the earth's surface emits black-body radiation at a higher temperature until the correct amount of energy is emitted to space. This then is the greenhouse effect (Ramanathan, 1989; Dickinson and Cicerone, 1986).

GREENHOUSE GASES

Observations of, and research on the sources and sinks of CO_2 commenced in the late 1950's in Hawaii and Antarctica, and was later followed by research by scientists in Australia and elsewhere. An important consideration in this respect was that following a rapid development in the field of atmospheric chemistry, it was realised that CO_2 was not the only infrared absorbing trace constituent which was accumulating in the global atmosphere. Other substances now recognized as greenhouse gases are methane (CH_4), chlorofluorocarbons (CFCs), nitrous oxide

(N_2O), and tropospheric ozone (O_3). Present-day observations of these gases (Pearman, 1988), as well as measurements of air trapped in Antarctic ice, which allows CO_2, CH_4 and N_2O concentrations to be traced back for hundreds (Pearman *et al.*, 1986) or even tens of thousands of years (in the case of CH_4 and CO_2; Barnola *et al.*, 1987) have by now firmly established that the currently observed rising trends are a relatively recent phenomenon (within the last 200 y), closely linked to population growth, land clearing and the industrial revolution. Details are provided in Tables 1 and 2, and Figures 1 and 2.

TABLE 1: Greenhouse Gases

Greenhouse gas	Concentration		Present trend (% per y)	Possible sources of increases
	Pre-indust (1850)	Current (1989)		
CO_2	275 ppmv	350 ppmv	0.4	Fossil fuel combustion, deforestation
CH_4	750 ppbv	1700 ppbv	0.8	Rice paddies, ruminants, biomass burning, gas & coal fields, land fills, tundra
CFC-11	nil	250 pptv	4	Industrial & consumer goods
CFC-12	nil	450 pptv	4	Industrial & consumer goods
N_2O	285 ppbv	310 ppbv	0.3	Biomass burning, agriculture, fossil fuel combustion
O_3(trop.)	15-20 ppbv	20-30 ppbv	0.5a	Urban and industrial pollution

[a] Estimated to be 1% in the Northern Hemisphere, 0% in the Southern Hemisphere.

The changes from pre-industrial times have been significant, with CO_2 increasing by 25%, CH_4 by more than 100%, and the CFCs, being totally man-made, not being present in the atmosphere prior to the 1930s. From the data presented it can also be seen that the actual concentrations of different greenhouse gases vary by up to a factor 10^6 when comparing CO_2 and CFCs.

The relative warming effect of the key greenhouse gases on a global basis is shown in Table 2.

In considering the importance of emissions of each of these greenhouse gases in causing global warming it is necessary to consider:

The effectiveness of a molecule of a greenhouse gas in trapping infrared radiation, allowing for the spectral distribution of terrestrial radiation and the overlap of absorption spectra for all radiatively important gases;

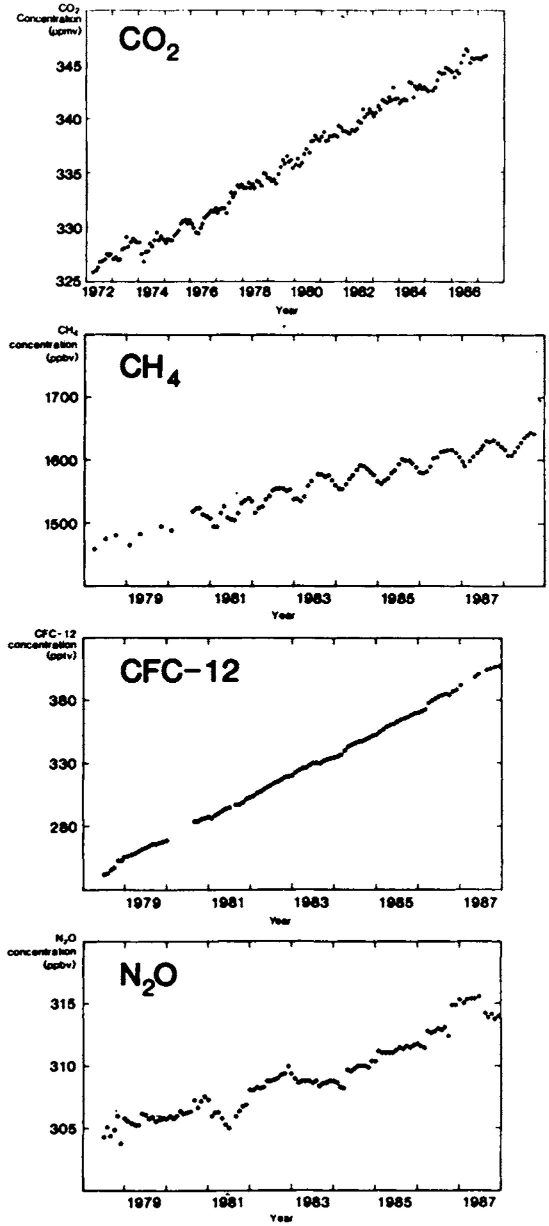

Fig. 1. Atmospheric trace gas concentrations measured over south-eastern Australia (CO_2) and at the Cape Grim Baseline Observatory, north west Tasmania (CH_4, CFC-12 and N_2O). Note that these Southern Hemisphere observations are somewhat lower than the global average, while the N_2O scale shown here is about 5ppbv too high. See Pearman (1988) for sources of data.

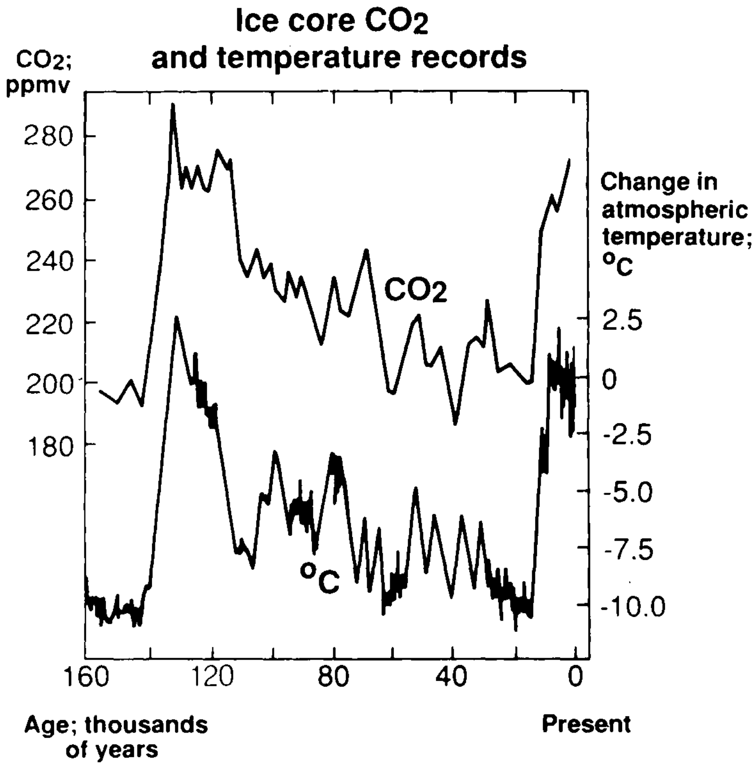

Fig. 2. Analysis of air from the Vostok ice core (Barnola *et al.*, 1987) clearly shows the strong link between atmospheric CO_2 and global temperature. It also shows that the CO_2 concentration had not been above 290 ppmv for the last 160,000 years. The current value is 350 ppmv, rising at 0.4% per year.

- The concentration of the gas; and
- The lifetime of the gas in the atmosphere. Clearly, a greenhouse gas that reacts immediately it is released into the atmosphere to become another species, is far less important than a gas that has a long residence time in the atmosphere.

Chlorofluorocarbons in particular are very effective because (i) their absorption occurs in a part of the infrared where neither H_2O nor CO_2 absorb (the so-called window), (ii) their absorption band strengths are significantly stronger than that of CO_2, and (iii) with the small amounts of CFCs in the atmosphere their impact is almost linear with concentration, while CO_2 is sufficiently abundant that it is optically thick, and its impact scales logarithmically with concentration (Ramanathan, 1988).

TABLE 2: Warming Effect of Greenhouse Gases

Greenhouse gas	Radiative forcing[a] (Wm^{-2})	Relative[b] radiative forcing per ppmv increase[a]	Atmospheric lifetime (y)	Long-term relative[b] contribution to global warming per molecule emitted	% of the total radiative forcing to date	% of the radiative forcing due to current increases
CO_2	1.3	1	60[c]	1	59	55
CH_4	0.6	36	10	6	27	20
CFC-11	0.06	14600	75	18000	3	6
CFC-12	0.12	17000	110	31000	6	12
N_2O	0.05	140	150	350	3	5
O_3(trop.)	0-0.12	430	0.2	1	2	2

[a] From Dickinson and Cicerone (1986), based on the increases in atmospheric concentrations from pre-industrial times to 1985.

[b] Relative to CO_2.

[c] The turn-over time for atmospheric CO_2 is about 6 years, but the time needed to permanently remove CO_2 to the deep ocean and the long-lived biosphere is about 60 years.

The current and past concentrations of most of the greenhouse gases are now well-known, while research into the sources and sinks of each of these gases is continuing. Although it is currently possible to make rough estimates of the sources, more accurate information is urgently needed in order to enable better estimates of future atmospheric levels to be made, and the impact of possible control strategies to be assessed (Pearman, 1988).

A benchmark increase often used in consideration of the greenhouse effect is the doubling of atmospheric CO_2 from 300 ppmv to 600 ppmv, an event which is expected by about 2075 AD. If, however, the contributions from anticipated rises in other greenhouse gases are taken into account, an effect equivalent to a doubling of CO_2 is likely to be reached by 2030 AD (Ramanathan *et al.*, 1985; Bolin *et al.*, 1986).

CLIMATE MODELLING PREDICTIONS

As explained above, the radiative forcing exerted by the increases in the various greenhouse gases can be calculated, and comes to about 4 Wm^{-2} for a doubling of CO_2. This, in turn is calculated to lead to an equilibrium surface warming of between 1.1 and 4.5 K. These calculations have been carried out using a range of mathematical models describing the global atmosphere, the most sophisticated of which are known as general circulation models (GCMs) (Tucker, 1988). The latter predict an equilibrium warming of 4 to 5 K (Ramanathan, 1988).

It is generally agreed that GCMs currently in use need a range of complex changes to increase their accuracy and their regional detail. The representation of soil hydrology, clouds, ocean/atmosphere interaction and a number of other processes needs to be improved. The spacing of the gridpoints around the globe at which key parameters are being calculated is currently too large (500-700 km) to allow detailed descriptions of regional geography and topography to be fed into the model. Nevertheless it is significant that all model calculations to date predict an increase in the global mean temperature (Bolin *et al.*, 1986; Ramanathan, 1988).

Finally, it should be pointed out that the GCM calculations are independent from the research on greenhouse gases. Research on the latter will provide us with estimates of when an effective doubling of CO_2 is to be expected. The GCM calculations will tell us what the climatic effect of such a doubling will be. It also needs to be noted that the effective doubling of CO_2 is an arbitrary target but not an end point. The increase in greenhouse gas concentrations, and therefore the resulting climatic change, is a continuing process. Lesser changes will occur prior to an effective doubling of CO_2, and greater changes after, as long as greenhouse gas concentrations are allowed to continue to increase.

CLIMATIC CHANGE

Although there are serious limitations to the detail that current GCM calculations can provide, a number of conclusions can be drawn from the results already. The most important general conclusion is that a global warming would not be uniform and would be accompanied by a change in all other parameters which make up global and regional weather and climate. Specifically, the warmer globe will be on average (but not everywhere) more humid and wetter; the warming will be least near the equator and greatest near the edges of the winter ice and snow cover; and as weather systems shift poleward, there may be a summer-drying in mid-latitudes (Ramanathan, 1988). Some of this information has recently been used to provide preliminary estimates of regional climate change (Pittock, 1988).

FEEDBACK PROCESSES

Atmospheric scientists are acutely aware that the ultimate outcome of the radiative forcing due to greenhouse gas increases is governed by the way the total climate system will respond. There are many feedback processes which can enhance or ameliorate the primary effect.

One such process is due to the extra surface warming leading to more evaporation. As water vapour is a greenhouse gas, this would result in a positive feedback which would increase the surface warming. A second feedback is linked to the observation that a surface warming will lead to reduced snow cover and less sea ice. This would reduce the amount of solar radiation reflected, and thus increase the warming at the earth's surface (to a lesser extent than the water vapour feedback, but very significant on a regional basis).

Another important feedback is that due to clouds, which play a major role in the earth's radiation balance, and which reflect a significant amount of the incoming solar radiation. Increased evaporation and increased levels of atmospheric water vapour are likely to lead to increased cloud cover. Low level clouds are known to have a net cooling effect due to their reflection of incoming sunlight, and thus can be expected to decrease any greenhouse warming. But high level cirrus clouds are known to be relatively more efficient in trapping infrared radiation, leading to an increase of the surface warming. At this stage it is not clear which of these two processes would dominate (Ramanathan *et al.*, 1989).

One other feedback process involves the oceans: given the heat-capacity of the oceans, the response of tropospheric temperatures will be governed by the response of the ocean surface to the global warming. If the radiative heating were to be sequestered to the deep ocean, the global warming would be significantly delayed.

Yet another feedback involves the role of the stratosphere and stratospheric ozone. The greenhouse warming of the lower atmosphere will be accompanied by a cooling of the stratosphere. This would under normal circumstances enhance the ozone producing processes. But the possible decline of stratospheric ozone due to the presence of CFCs will reduce the amount of incoming solar radiation trapped by the stratosphere, allow this radiation to reach the earth's surface and thus add to any tropospheric warming. The magnitude of this warming would be small compared to the warming due to increases in greenhouse gases in the lower atmosphere.

Finally, it should be noted that there may be a range of other, perhaps minor, feedback processes which at this stage are too poorly understood to be included in climate change considerations. One such process concerns the possibility of the marine production of dimethyl sulfide (DMS) (known to be involved in cloud condensation) being perturbed by climatic change. More DMS might lead to more cloud, and hence act as a negative feedback (Charlson *et al.*, 1987). Feedbacks involving changes in the vegetation cover, and thus the surface reflectivity, roughness and evaporative cooling will almost certainly be of local significance, but may be less important on a global scale, especially in the Southern Hemisphere which is dominated by the oceans.

EVIDENCE FOR CHANGE

Model calculations show that the increases of greenhouse gases to date have already committed the planet to an equilibrium surface warming of between 0.6 and 2.4° C. A large uncertainty is how much the actual warming will lag behind. The available record of the global average temperature suggests that there has been a warming of about 0.5 K over the last 100 years (Jones *et al.*, 1988), but there is no certain way as yet of establishing which of a number of possible causes is responsible for this rise, especially when one looks at the variation in the trend from decade to decade (Figure 3). It is easy to see too, that similar analyses of regional trends would have to be treated with even more caution.

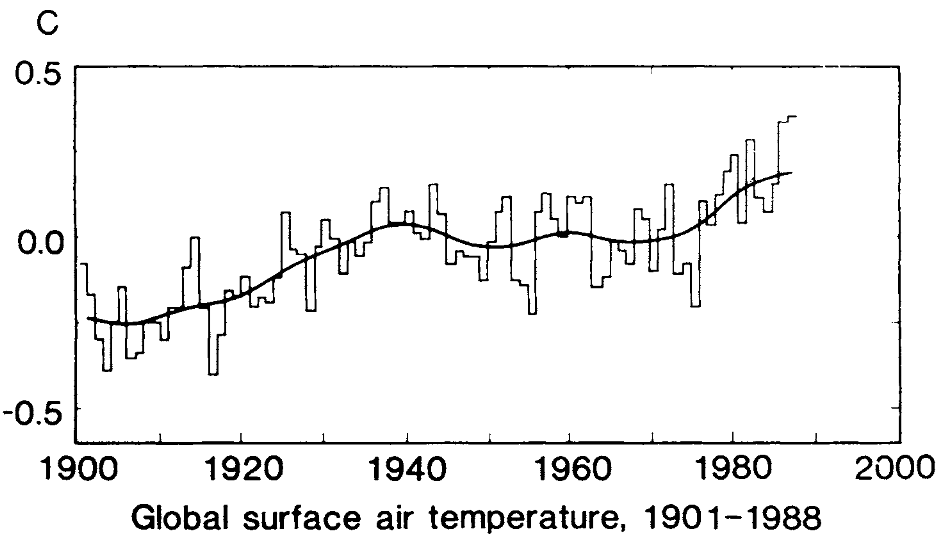

Fig. 3. The global temperature record relative to the 1950-1979 average from Jones *et al.* (1988) with 1987 and 1988 added.

While it is possible that climatic change is already in train, there will be an extended period where all the information on change in temperature, rainfall and extreme events will have to be assessed in the light of natural variability of weather and climate. In the face of this it should be remembered that the evidence of changes in the composition of the atmosphere is firm, irrefutable, and clearly linked to consequent climatic change. It is only a matter of time before it will become evident in the climatic measurements.

SECONDARY IMPACTS

A changing composition of the global atmosphere has a number of secondary impacts which need to be pointed out. Firstly, any global warming will result in some sea-level rise. This is due to two processes. One is the thermal expansion of the surface layers of the oceans which will warm along with the troposphere, the second is the increased melting of temperate ice (glaciers). For a doubling of CO_2 it is estimated that these effects would raise the global sea level by 20 to 50 cm (vander Veen, 1988). How much this sea-level rise would lag behind the surface-temperature rise is uncertain. Melting of the Antarctic ice cap is definitely not a risk for hundreds of years (Budd, 1988).

Perhaps less appreciated, but certainly important, is another consequence of atmospheric change: the fact that higher levels of atmospheric CO_2 will stimulate plant growth. Carbon dioxide is a known 'fertilizer' which in addition discriminates between different types of plants (Gifford, 1988), and this may add a very different aspect to the considerations of the impact of climatic change.

A further outcome of a changing atmosphere and global climate change which almost by definition is impossible to predict is the element of surprise. The mechanisms which govern the sources and the sinks of the atmospheric trace gases such as CO_2 and CH_4, and the mechanisms of ocean/atmosphere dynamics which determine the global climate are sufficiently complex that scientists cannot rule out the possibility of unforeseen sudden changes. Examples of such events are provided by the recent discovery of stratospheric ozone loss over Antarctica (Farman *et al.*, 1985; Fraser, 1989) and the observation from geological evidence that the global ocean circulation has in the past shown sudden and dramatic changes (Broecker,1987).

MISCONCEPTIONS

A number of misconceptions need to be laid to rest. These are:

- The greenhouse effect is only a theory.
  Incorrect. In its most fundamental form the greenhouse effect is a well established physical process, while the evidence of recent increases in the concentration of so-called greenhouse gases in the atmosphere is incontrovertible.
- The greenhouse effect is based on observed rising temperature and/or sea-level trends.
  Incorrect. The scientific debate is firmly based on the observed changes in atmospheric composition. The observed temperature and sea-level trend, although consistent with the chemical changes, only serve as circumstantial evidence which may or may not be linked to the greenhouse effect.
- The additional CO_2 would not trap any extra outgoing infrared radiation, as all of it is already being trapped.
  Incorrect. Although the absorption bands of CO_2 are almost saturated, increases will still contribute to the greenhouse effect. It is true that CH_4 and CFCs are more effective because they absorb in an otherwise clear part of the infrared spectrum—all these properties have been taken into account.
- Cloud feedback might lead to a cooling rather than a warming.
  Incorrect. As stated earlier, cloud feedback is certainly one of the aspects ill-described by current GCMs. But as it is a **feedback process,** one would still need a warming to even start this feedback, and thus in the first instance this process could slow down, but not prevent, far less reversal, a global warming.
- If weather prediction cannot get the forecast reliably beyond a few days, climate prediction would have to be a futile exercise.
  Incorrect. Although both types of effort have the physical description of the atmosphere in common, they deal with very different scientific problems. In weather prediction an instantaneous description of the atmosphere and all its properties is required. Climate modelling, by contrast, deals with statistical averages which are calculated quite differently. We can describe these average properties without necessarily having to describe in detail each individual weather event.

OPTIONS

There are two major options open in responding to climate change induced by increasing levels of greenhouse gases. These are adaption and avoidance. We can allow the concentration of the gases to continue to increase, and adapt to any changes in climate that this brings about. Alternatively, we can decide that the economic, social and environmental impacts of such changes are so large that we attempt to reduce the emissions of the gases and thus slow down the rate at which future changes will occur. Some climatic change appears to be inevitable, given the changes that have already been set in train, and the obvious difficulty of slowing down the releases at short notice. Yet, it seems that we cannot go on indefinitely allowing the planet to warm. At some time control measures will be needed. It is widely accepted that given the timescale necessary to make significant reductions to the emissions, efforts should commence now to achieve these long-term goals.

SETTING GOALS FOR EMISSION REDUCTION

During the 1988 international meeting on *The Changing Atmosphere; Implications for Global Security*, held in Toronto, the conference developed a goal for the reduction of CO_2 emissions. It was stated that attempts should be made to reduce global emissions by 20% by the year 2005. Several points should be made about this goal. First, there appeared to be little theoretical analysis made as to just what this goal would actually achieve. It was some kind of qualitative acceptance of a balance between what might be desirable and what might be achievable. Second, subsequent analysis shows that given the current state of the global carbon cycle, embarking on a global negative growth in CO_2 emissions of 1.5% y^{-1} would achieve a significant slowing down of the rate of increase of CO_2 in the atmosphere and a quasi-stabilization of CO_2 levels in the atmosphere below the 400 ppmv level about half way through the next century (Figure 4). Such a rate of reduction of emissions would lead us to a condition of about 20% reduction in emissions by the year 2005, but continuing on to a reduction of about 50% in the next 50 years. That is, it must be realized that reductions of greater than 20% will be necessary in the longer term if stabilization of the concentration is to occur, and that negative growth rates of CO_2 emissions of about 1.5% y^{-1} is what is needed.

All of this should be considered in the perspective of what has happened to emissions of CO_2 historically. Through much of the last 150 years, developing nations have experienced growth rates in energy consumption that have lead to annual growth of CO_2 emissions of about 4.5% y^{-1}. Exceptions to that have occurred during the World War periods and the last decade following the oil embargos of the mid 1970s, when growth rates, globally of about 1-2 % y^{-1} have occurred. Thus to embark on negative growth rates of CO_2 emissions will be unprecedented in industrial history. It is true, that during the last ten years the growth rate of energy usage in developed nations has been close to zero (Australia excepted), whereas for

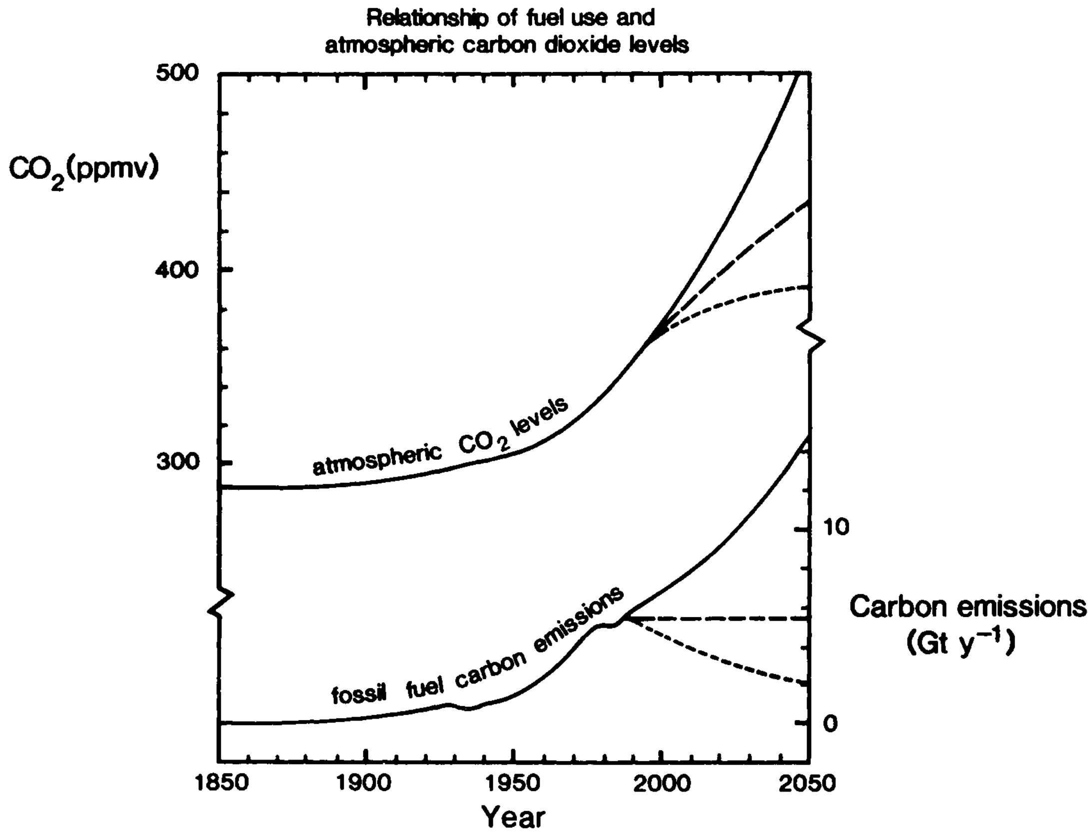

Fig. 4. The predicted relationship between global atmospheric CO_2 due to the use of fossil fuels. The diagram illustrates the economy difficulties to be encountered in bringing about substantial control of the current CO_2 increase. Calculations based on the carbon cycle model of Siegenthaler and Oeschger (1987).

the developing nations a rate of 4-5% y^{-1} has been maintained. This points to one of the difficulties in achieving global reductions of emissions, while the developed nations may be expected to increase their per capita consumption. It may be necessary for developed nations to take a disproportionate share of any attempt to reduce emissions.

AUSTRALIA'S GREENHOUSE GAS EMISSIONS

Table 3 shows the approximate relative contribution of Australia's emissions of various greenhouse gases to global warming. Such a Table gives some guide as to the emphasis that might be placed on attempts to limit emissions of one kind or the other. Of course, the practicality and costs associated with reducing one emission or the other will vary widely and also influence any emission control policy.

TABLE 3: Relative Warming Effects from Australia's Emissions of Greenhouse Gases

Gas	Source	Annual ($Mt\ y^{-1}$)	Emissions ($Mmoles\ y^{-1}$)	Relative greenhouse contribution per molecule emitted (From Table 2)	Relative contribution to greenhouse effect (%)
CO_2	Coal	158	3.6	1	27
	Liquids	72	1.6	1	12
	Gas	25	0.6	1	5
	Total	255	5.8	1	44
CH_4	Ruminant animals	2.2	0.14	6	6
	Other animals	0.2	0.01	6	1
	Rice	0.2	0.01	6	1
	Mining operations	0.3	0.02	6	1
	Land fill	1.5	0.09	6	4
	Natural gas grid	0.2	0.01	6	1
	Biomass burning	2.0	0.13	6	6
	Total	6.6	0.41	6	19
N_2O	Primarily agric.	0.3*	7×10^{-3}	350	19
CFCs	Refrigeration, etc.	0.012**	9×10^{-5}	25000	18
Ozone	Not significant in Southern Hemisphere				0

* Very uncertain estimate.

** Average characteristics of CFC-11 and CFC-12 used.

Research is needed to further improve the confidence associated with the numbers in Table 3. However, we believe that such research is not likely to change the major relative features of the data.

Australia's strict adherence to the Montreal Protocol for the limit of ozone destroying substances will clearly make substantial contributions to the national reduction of the growing in the greenhouse effect.

COMMENTS CONCERNING OPTIONS

Developing policy options of these kinds is not the role of atmospheric scientists. However, experience with the field in general leads us to several overall impressions that may be of value to those who have this responsibility.

Australia's responsibility

Australia's contribution to the level of greenhouse gases in the atmosphere is of the order 1-2% of the global contribution. It might be argued, therefore, that what we do to curb emissions will be globally insignificant. Even expensive and socially disruptive reductions to Australia's release of CO_2 and other greenhouse gases, would have little impact on the changing global climate unless other nations take part in such actions. Sections of the Australian community have already used this to argue their immunity.

The same argument could have been used with respect to the CFC-ozone depletion issue. Instead, Australia took a leadership role by actively participating in the development of an international protocol and then passing legislation to ensure national compliance.

Australians use 50-100 times more energy per capita than Indians and Chinese. Infact, on a per capita basis, we are amongst the worst contributors to CO_2 emissions into the atmosphere.

Thus a strong moral argument can be made that we have no right to expect one billion Chinese to control the level of their CO_2 emissions below those we use to provide our standard of living. However, if they were to develop to our level of per capita consumption, this would contribute enormously to CO_2 increase in the atmosphere. Similarly, how can we call on the current major contributors to CO_2 emissions (e.g. USA) and ask them to reduce their per capita emissions below ours?

Package approach

There is no single most important contributor to the CO_2 or CH_4 emissions into the atmosphere in Australia. For example, there is no single "fix" which can be used to substantially reduce our CO_2 emissions. What is needed is an examination of all areas of energy utilization and the identification of methods for the reduction of CO_2 emissions via the options of:

- Energy conservation;
- Improved energy-use efficiency;
- Alternative energy resources (solar, nuclear, renewable, etc.); and
- Changes to the proportions of energy generated by the various fossil fuels as some are more energy 'efficient' in terms of CO_2 emissions than others.

Policy based on such an examination would be developed with due consideration of the effectiveness of the "package" of changes implemented to reduce CO_2 emissions and the economic, sociological and environmental costs incurred in making the adjustments.

Considerations similar to those given for CO_2 will also need to be applied to gauge the extent to which reductions in CH_4 and N_2O emissions can be achieved. For CFCs this process is already in train, and can even serve as an example.

Preparedness to make policy assessments

The Australian energy community is currently ill-prepared to provide the assessments necessary for a comprehensive policy to be developed. There has been some natural reluctance to accept changes, particularly as these relate to a threat which is poorly understood by the energy community. At this point in time, most of those industry-related assessments have tended to start with the premises that growth in energy usage will continue, and that particular sectors of the energy community should be protected. Such positioned arguments, similar to the anti-nuclear stance, have not been particularly objective.

Recognizing the above, last year, CSIRO through its Institutes of Minerals, Energy and Construction and Natural Resources and Environment, commenced organizing a National Conference on Greenhouse and Energy: Australia's Options, to be held at Macquarie University, December this year. The objectives are:

- To provide a forum for the rational presentation of opportunities in Australia, in all areas of the energy sector, to reduce CO_2 emissions;
- To encourage the assessment of economic, societal and environmental costs associated with these opportunities;
- To promote research into energy systems and alternatives for reducing CO_2 emissions in Australia; and
- To publish a document based on the reviewed proceedings of the meeting which will provide policy-makers with a set of options from which choices can be made.

The Federal and State Governments will need these evaluations before substantial policy changes can be implemented. Further, it is most likely that the "mix" of options most appropriate (maximum CO_2 reductions—minimum economical and societal disruption), will be different for example, for Victoria than New South Wales, and different for Australia than for, say, Switzerland.

Acting now

It is suggested that the issue of climate change is sufficiently important that policy initiatives should not be delayed until research has examined at length all options. But it is prudent that it is recognized that we are in a state of rapidly changing information with respect to knowledge of the greenhouse effect, its impacts, and our capacity to adjust and the options for avoidance.

CONCLUSIONS

Considerations of the greenhouse effect have by now moved from the realms of academic curiosity to a position of conviction that global warming is a highly probable expectation for the future. While there are a number of loose ends to be tied up, there is now amongst atmospheric scientists a realisation that the problem has implications and interactions far beyond their restricted domain. The time lag between atmospheric change and climatic change, and between climatic change and sea-level rise, is such that what we do or do not do today has significant repercussions for generations to come. If one accepts this premise, then the need to research what those changes might be, and the need to assess how greenhouse gas emissions might be controlled becomes obvious.

The task of carrying out research aimed at providing more detailed information concerning potential climate change for the Australian region is currently being undertaken by CSIRO scientists in collaboration with scientists in the Bureau of Meteorology, and in close collaboration with the various Australian States and some colleagues in the Universities.

The task of planning reductions in the various greenhouse gases has only just commenced. CFCs are to be controlled soon, mostly because of their stratospheric ozone depleting properties. Methane and N_2O may be difficult to control. Carbon dioxide, being linked so closely to fossil fuel use is amenable to reductions, but many aspects need to be considered. One such aspect is the amount of CO_2 emitted for a given fuel source (Table 4). Fuel switching, energy conservation, and a move towards renewable energy will probably all have to be explored to offer any prospect of significant CO_2 emission reductions. It is unlikely that there exists a single solution to CO_2 emission reduction. Instead there will be a need for a'package' of changes. Determining what this package should consist of, and what is appropriate for one state or the other, or one country or the other, is a matter for urgent attention. Obviously any changes in the energy area will have economic consequences, but so too will uncontrolled climatic change and sea level rise.

TABLE 4: Carbon Emissions from Fossil Fuels[a]

Fuel	Energy content (MJ/kg)	Carbon[b] content (%)	Carbon[b] emission (kg/GJ)	CO_2 emission (ratio to natural gas)	Australian CO_2 emission by sourcec[c] (%)
Natural gas	50.0	75	15.0	1	11
Oil	42.0	84	20.0	1.3	35
Black coal	23.0	65	28.3	1.9	40
Brown coal	7.7	24	31.2	2.1	14

[a] Adapted from figures provided by the Australian Institute of Petroleum.

[b] CO_2 emissions are generally measured by their weight as carbon.

[c] Data for 1987. Total Australian CO_2 emissions are about 1.5% of the globalemission of about 5 Gt (measured as carbon).

Tree planting has recently been suggested as a method of countering the greenhouse effect. However, the sheer magnitude of the task at hand needs to be kept in mind. Ten billion trees, occupying 10 million ha, planted today, would take up enough CO_2 to reduce the world's annual CO_2 emissions from burning fossil fuels by about 1% (Marland, 1988). Thus it should be clear that, while planting trees will be good for many other reasons (to stop land degradation, maintain ecosystems, etc.), as a means of countering the build-up of atmospheric CO_2 it can have a significant effect, but only if carried out on a large enough scale.

That the atmospheric changes have already committed the earth to a global warming, and that it will be well-nigh impossible to stop any future change should be clear by now. We are left with the task of planning for the change and limiting the ultimate magnitude of the change. How exactly we will tackle these issues remains to be seen.

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