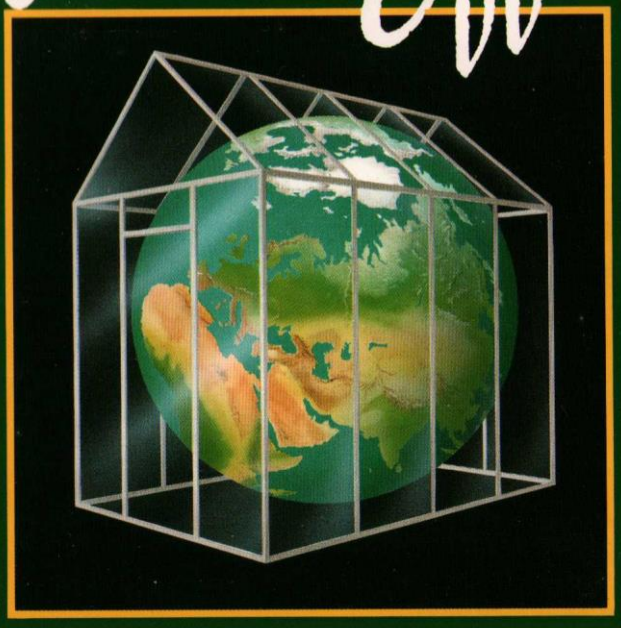
NUCLEAR POWER AND THE Greenhouse Effect



About the authors:

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Contents

1. We hear a great deal today about the Greenhouse Effect and the changes it could bring to our climate. The world is expected to get hotter, the weather to become more variable and patterns of rainfall to change. These changes could result in many harmful effects on people's lives in the future. Why should this be, how much of a threat do we face and what can be done about it?

The Greenhouse Effect

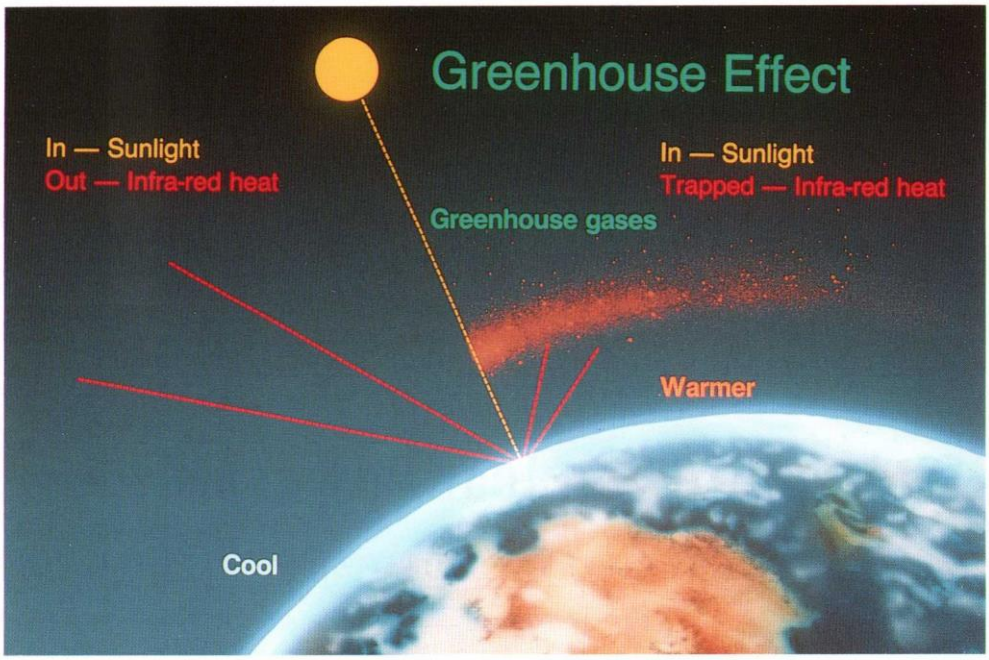


Figure 1. *How the Greenhouse Effect works*

WHAT IS THE GREENHOUSE EFFECT?

2. Sunlight passes through the air and, on reaching the ground, turns into heat (Figure 1). Certain gases including water vapour act as a "blanket" preventing some of this heat escaping back into space – rather like the glass in a greenhouse. The amount of heat that is trapped depends on the quantity of "Greenhouse" gases in the atmosphere, and it is their presence that helps keep the Earth comfortably warm – without it we would freeze.

3. This all-important level of Greenhouse gases in the atmosphere results from a balance between emissions from natural sources (mainly of carbon dioxide and methane) and their subsequent removal or destruction. Mankind is disturbing this balance by emitting additional large amounts of nature's Greenhouse gases, and by adding some new ones such as the chlorofluorocarbons (CFCs) that are used in aerosol cans and in refrigerators and are already well known because they also destroy the ozone layer. The worry is that these man-made emissions will add to the warming effect, and that this will bring about damaging changes in climate.

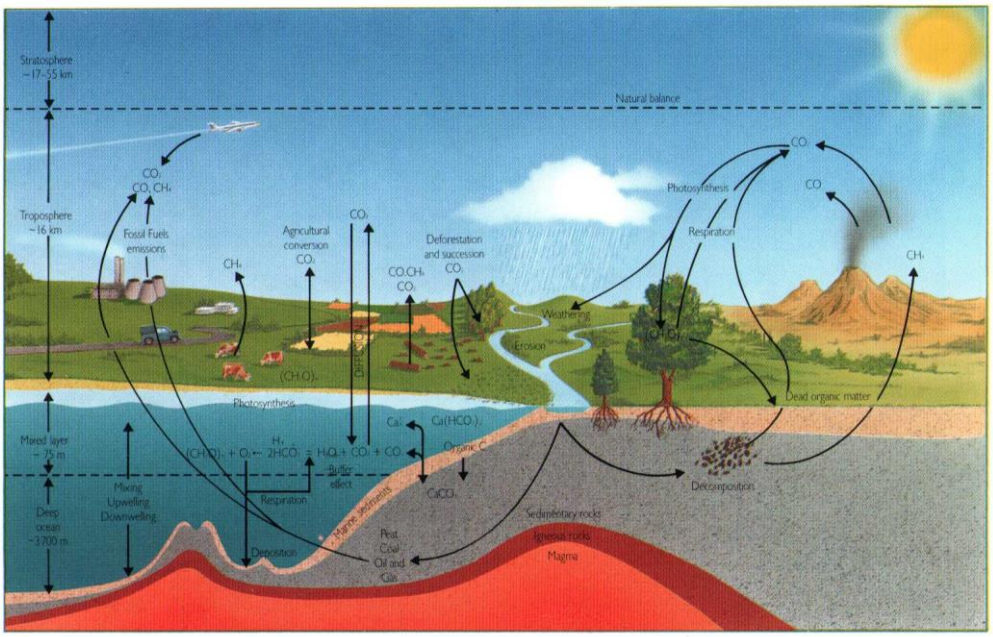


Figure 2. *Exchange of Carbon in Nature – Complicated, isn't it?*

WHAT IS THE EVIDENCE FOR IT?

4. We already know from measurements taken around the world that levels of some of the Greenhouse gases are increasing. For example, carbon dioxide –one of nature's Greenhouse gases with a complex natural cycle (Figure 2) – has already built up from its pre-industrial balance in the atmosphere of about 275 parts per million (ppm) to around 350ppm as a result of man-made emissions and is still increasing. Increases have also been observed in the levels of methane and the CFCs.

5. We are aware that something seems to be happening to our weather. Average world temperatures have generally increased over the last century (Figure 3). Seven of the warmest ten years since records began to be kept in the 1850s have been in the last decade, with 1988 followed by 1987 being the two hottest. Even so, we cannot say for certain that increasing amounts of Greenhouse gases are the cause; alternative natural explanations are possible. Moreover, between 1940 and 1960 world temperatures dropped despite Greenhouse gases continuing to be pumped into the atmosphere by mankind's activities.

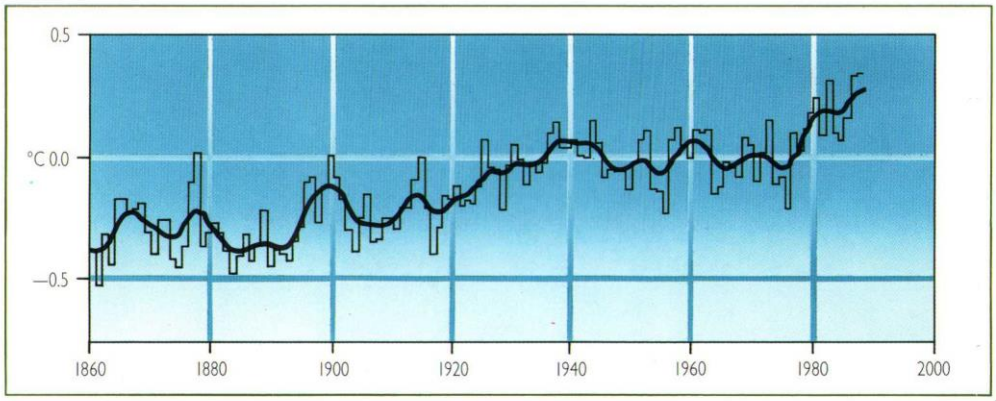
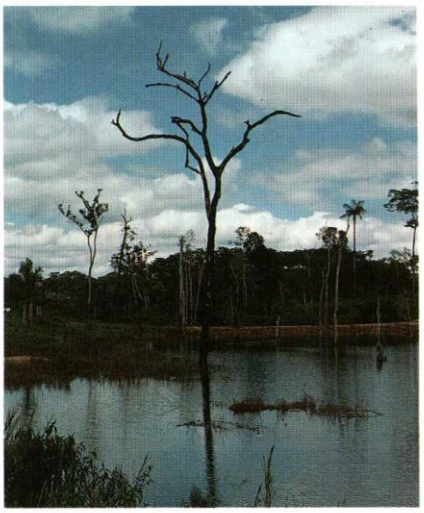


Figure 3. *Global Warming*



Flooding in Brazil

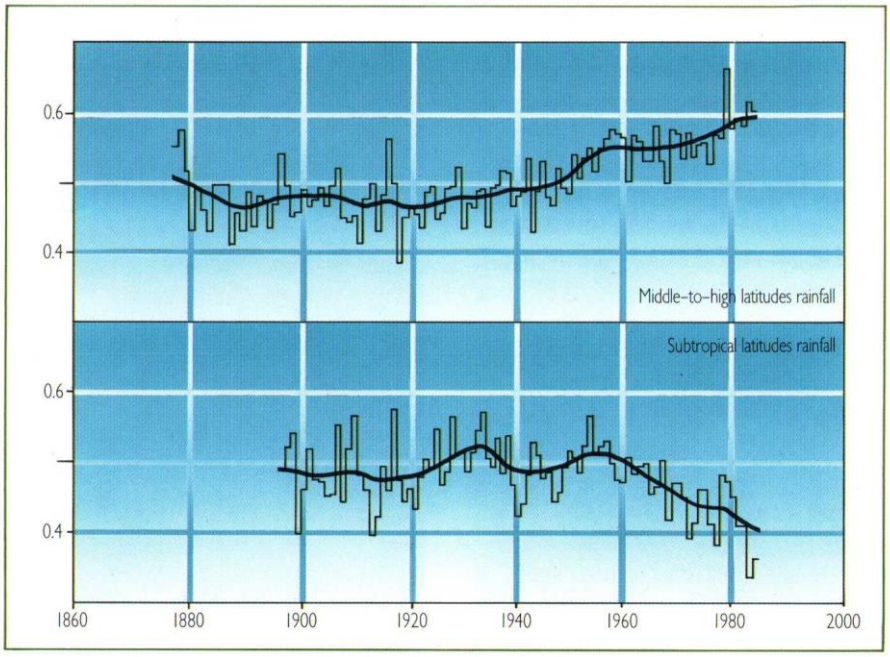
6. Weather patterns also seem to be shifting and extreme events becoming increasingly common. The great storm of 1987 in Southern Britain is one such example, and in recent years there have been other examples around the world.

In Egypt the Aswan High Dam has been short of water; in both Ethiopia and the US corn belt there have been droughts; in Mexico and Brazil there has been serious flooding.

Rainfall patterns seem to be changing (Figure 4). In the middle to high latitudes rainfall has risen steadily over the last 20–30 years, whereas in the sub-tropics there has been a marked decrease.

Severe storm damage in Britain, October 1987

Parched land in USA grain belt



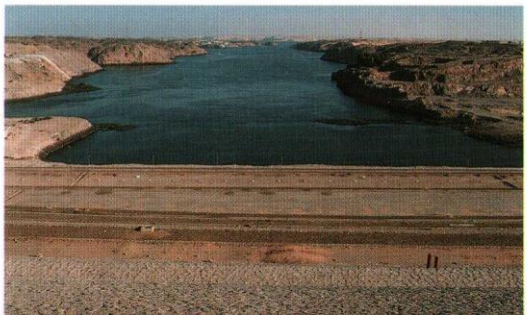


Figure 4. *The World's rainfall*

Footnote: *The picture shows the relative change in rainfall over the last century at different latitudes*

Water levels have recently been low in the Aswan High Dam

7. However, it is too early to see all these changes as firm supporting evidence of the Greenhouse Effect. This can only come from confirmation of global temperature increases over an extended period. Nevertheless, it is generally believed that the most likely explanation of the changes is the Greenhouse Effect, but with the trend hidden at times by natural variations, especially in temperature.

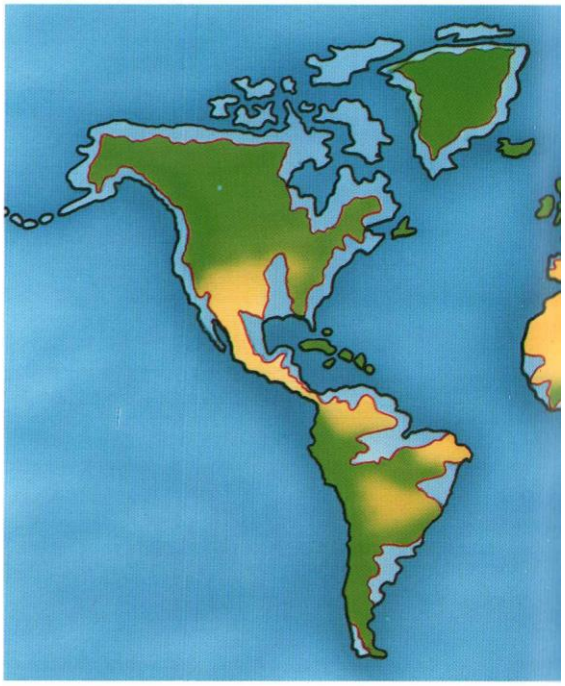
WHY WORRY ABOUT IT?

8. Mankind has been pumping waste gases into the air for a long time. Worlwide we are now polluting the atmosphere faster than ever before and threatening his environment. We are at last waking up to some of the effects of this pollution, notably that:

☐ "acid rain", formed by emissions from burning fossil fuels (coal, oil and gas) dissolving in raindrops, is damaging lakes, soils, plants, animals, forests and fisheries, as well as attacking buildings and metal structures;

☐ CFCs, from aerosol sprays and refrigerators, are damaging the ozone layer which protects us from the sun's harmful ultraviolet light, and this could lead to more skin cancer and eye damage.

Efforts are now being made to do something about these emissions.



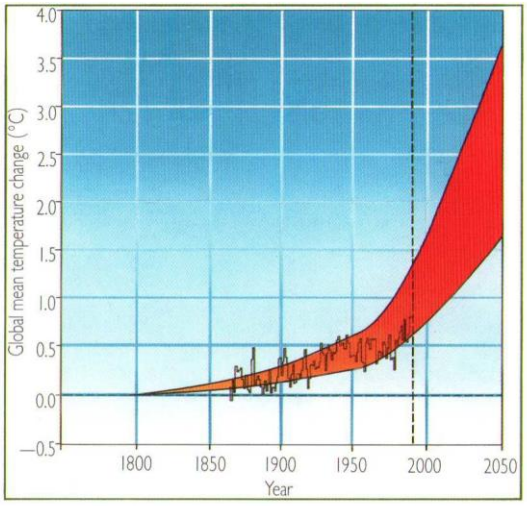
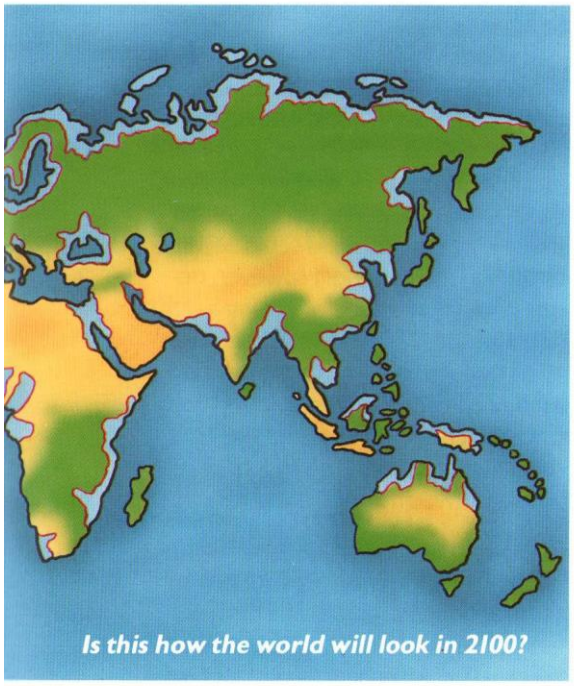


Figure 5. *Observed and predicted temperature change*

Footnote: *We expect global temperature in the future to lie within the coloured band. So far observation (the jagged line) and predictions have spread fairly well*



9. However, it is becoming increasingly recognised that a much more serious problem could arise from the emission of the Greenhouse gases. Unfortunately, because the Earth's climate mechanisms are so extremely complex, predictions of what could happen are very uncertain. Average temperature could rise by between 1½ °C and 3½ °C within 50 years – very fast by natural standards (Figure 5). Such global warming, particularly at the top extreme, could have far-reaching effects as a result of higher sea levels (from thermal expansion and from melting ice-caps and glaciers), altered rainfall patterns and more extremes of weather. The increased carbon dioxide levels would affect plants. Some of the results of these changes could be:

☐ an increased number of storms, like the hurricanes in Jamaica in 1988 and 1989;

Damage by hurricane – Jamaica 1989

☐ flooding of low–lying land (estimates of sea level rise have varied from a few centimetres to a few metres);

☐ shifts in the food growing areas and less security of supplies because of droughts and soil erosion in some areas and wetter conditions in others;

Endangered by warming

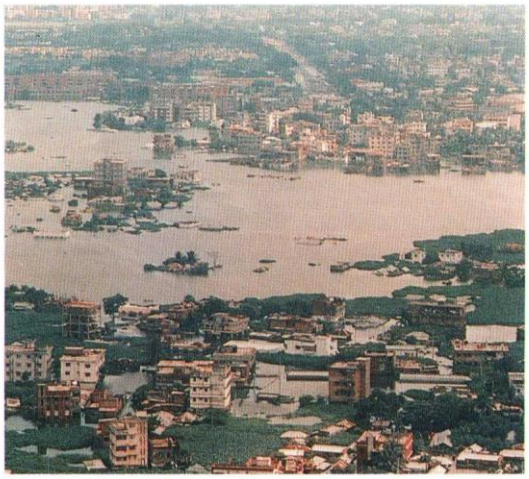
☐ extinction of some animal and plant species because they cannot accommodate to the rapidly–changing conditions.

☐ loss of supplies of fresh water in some areas because of the changing pattern of rainfall;

The effects would not be uniform and some regions would be affected more than others; some could end up as winners and some as losers. For example, the American corn belt could move further north, and parts of Russia that are frozen wasteland could become fertile agricultural land. However, no–one could guarantee being a winner, and even the winners would be likely to go through an uncomfortable period as they adapted to the new conditions. On balance the sufferings of the losers seem likely to be so high that they would outweigh any possible benefits to the winners.

10. The social disruption caused by these changes could be serious. The world is likely to see "Greenhouse refugees" as low–lying land is flooded.

The Maldives with more than a thousand islands are nowhere more than six feet above sea level, while countries like Bangladesh would face special problems as recent flooding in that area has shown. Drought could destroy farming communities in places like Oklahoma, and leave ghost towns and areas of desert. Severe climate changes of this nature would require major movements of population. Disruption on this scale would cause famine in many regions. The pressures on various peoples and countries would almost certainly lead to civil unrest, and maybe even war.



Flooding in Bangladesh – 1988

Abandoned farmstead, Oklahoma 1937. Could this happen again?

11. Overall therefore, the world could soon be facing a major, if not catastrophic, problem as a result of mankind's continuing pollution of the Earth's atmosphere. Indeed an international conference held in Toronto during 1988, said that "the ultimate consequences (of the Greenhouse Effect) could be second only to a global nuclear war". Consequently, we cannot afford to wait until we know how severe the problem will be before we start to take action.

WHAT CAN WE DO ABOUT IT?

12. It is probable that Greenhouse gases already released into the atmosphere will have committed us to some limited global warming in years to come, but we should be able to live with it. However, unless we reduce the rate at which we are polluting our atmosphere we will almost certainly have to adapt to severe climate changes. We ought therefore to try to minimise the amounts of Greenhouse gases that we push into the atmosphere, and even eliminate them wherever possible. In this way we could limit the rise in world temperature and the extent of associated climate change. But to achieve such reductions we have to know the sources of the Greenhouse gases and then to see what we can do about them.

13. Greenhouse gases come from mankind's need for energy, from agriculture and from industrial production. Figure 6 shows the relative importance of today's emissions of the main Greenhouse gases to the expected global warming. It should be noted that some of these Greenhouse gases are

Gas	Concentration (parts per million)		Relative Effectiveness (per molecule)
	Pre-Industrial	Now	
Carbon Dioxide	275	350	1
Methane	0.8	1.7	27
CFCs	–	0.001	15,000 – 25,000
Nitrous Oxide	0.28	0.31	165
Ozone (in the troposphere)	Meaningful values cannot be given to the ozone in the lower atmosphere because its concentration varies greatly from one region to another and its behaviour is very complex.		

Figure 6. *Effectiveness of Greenhouse Gases*

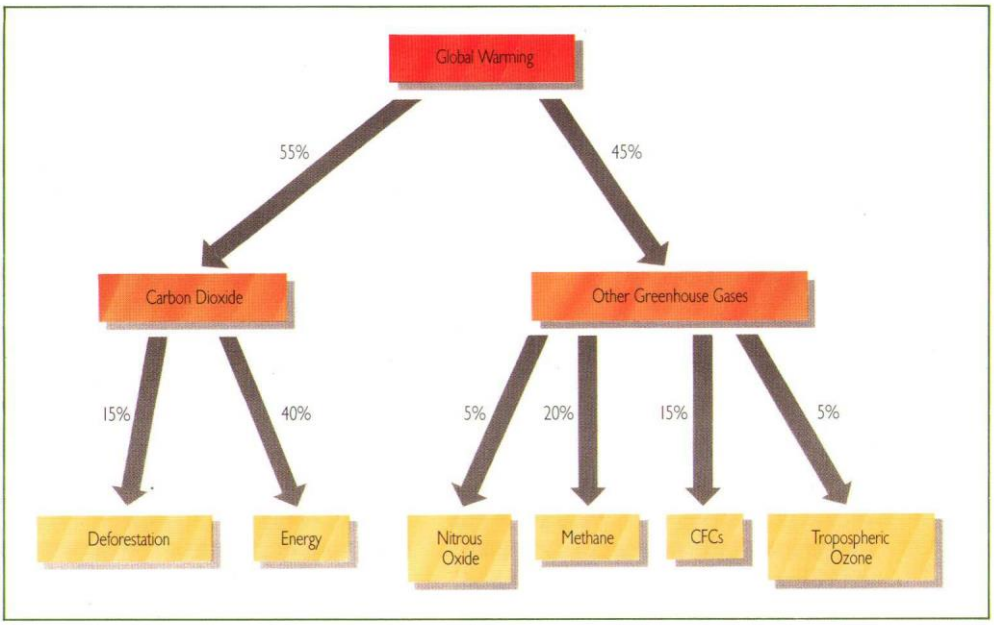
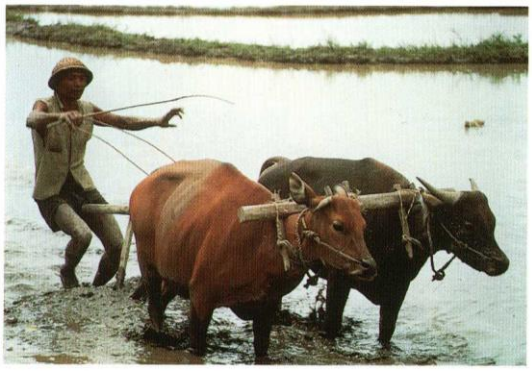


Figure 7. *Causes of Warming*

much more effective than others as can be seen from the table. For example, the CFCs are about 20,000 times more powerful than carbon dioxide. However, as their emissions are small compared to the huge quantities of carbon dioxide emitted their overall effect is not as big.

14. Some of these sources can be more readily controlled than others:



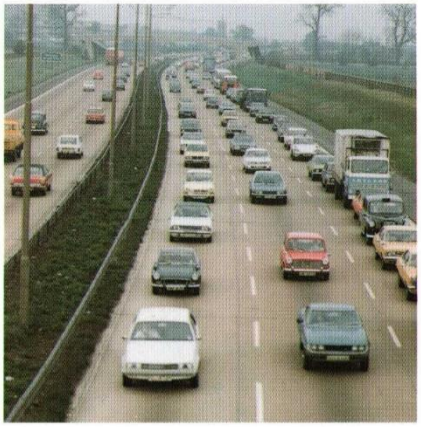
☐ most methane and nitrous oxide emissions are tied to agriculture and will be hard to reduce, although changes in agricultural practice might help.

Growing world population will result in increased emissions of these gases, so population control would help in the long term;

☐ much of the rest of the methane and nitrous oxide emissions is related to energy. The methane arises from escapes of natural gas and from coal mining, and may be difficult to reduce substantially. The nitrous oxide emissions arise from combustion of fossil fuels and will be reduced to some extent by clean burn technologies;

☐ CFCs are used mainly in aerosols, refrigerators, air conditioning units, and foamed plastic material. Their use could be reduced or even eliminated entirely

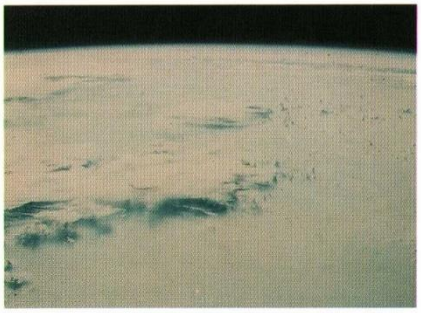
by replacing them with less harmful alternatives. Action is already being taken on a worldwide scale because of



Cars are a major source of nitrogen oxides

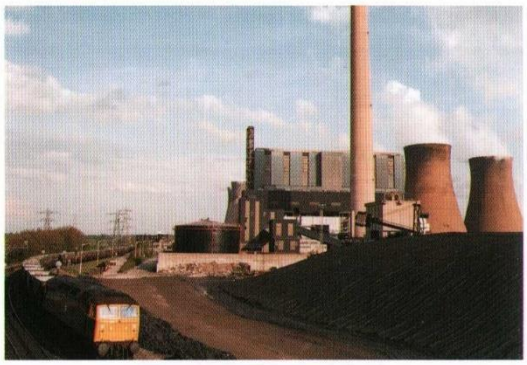
their destruction of the Earth's protective ozone layer in the upper atmosphere (stratosphere), and attention is also being paid to the Greenhouse properties of possible substitutes;

☐ ozone is building up in the lower atmosphere (troposphere) as a result of reactions involving oxides of nitrogen (NOX) released during combustion. Although this ozone could compensate to some extent for loss of that in the stratosphere, its effectiveness as a Greenhouse gas, associated with its other damaging properties in the lower atmosphere, more than outweigh any benefits. The problem of NOX is already being tackled because it



Deforestation and burning over the Amazon basin – so much smoke you can see it from space

(Photo from space shuttle Discovery)



Coal–fired power stations are also a major source of nitrogen oxides

contributes to acid rain, and any reduction in emissions will also reduce the build–up of this tropospheric ozone;

☐ deforestation contributes to higher carbon dioxide levels in the atmosphere because of the loss of growing trees that absorb carbon dioxide and, additionally, because many of the felled trees are burned and so emit carbon dioxide. Most deforestation occurs in poorer countries; if they are to be encouraged to stop, the richer countries will have to help them to develop alternative ways to better standards of living. Planting new trees would help to redress the balance but would have to be on a massive scale to have much effect; a new forest the area of Mexico

would cut our current carbon dioxide emissions by almost 15% whilst it was growing;

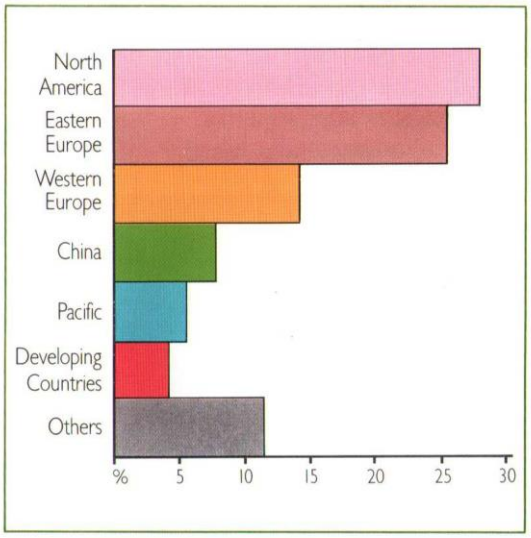


Figure 8. *Global CO_2 emissions by region*

☐ carbon dioxide from burning fossil fuels can be reduced in a number of ways. The most direct would be to make more efficient use of the heat produced and so reduce the amount of fuel needed. Other options would be to use fuels which emit little or no carbon dioxide.

15. It must, however, be recognised that the Greenhouse Effect is a global problem and as such requires a global solution. No one country, not even the USA which is responsible for much of the world's Greenhouse gas emissions or the USSR, which is also a major contributor, can solve it. Moreover, the developing countries with their rapidly–increasing populations cannot be expected to accept major restrictions on improving their often very low standards of living. The developed countries, and that includes the UK, will therefore have to take the lead.

The Role of Energy

16. Whilst all sources of Greenhouse gases must be tackled, the largest single contributor is carbon dioxide from the energy sector (from now on referred to as "energy–CO_2"). This is produced by burning fossil fuels and currently accounts for around two–fifths of global warming emissions as Figure 7 on page 12 shows. What can we do to reduce emissions of this energy–CO_2? First, we must examine our energy needs and reduce these as much as possible.

HOW MUCH ENERGY DO WE NEED?

17. Energy is central to the high standard of living in the developed world and to the hopes of people in the poorer developing countries of living longer and better lives. People need the services that energy provides – clean water and health care, food production, heating and lighting, industry and

transport, and so on. What fuels are used to meet the energy required will determine how much carbon dioxide is emitted by the energy sector.

18. It is vital that we use fuels efficiently, since the less fossil fuel we use the less carbon dioxide we emit. Improving energy efficiency in the home, in transport and in industry is essential. It is important that we speed up the process as much as possible, and this will require a wide range of action by many different consumers. For a developed country like the UK, these actions would include:

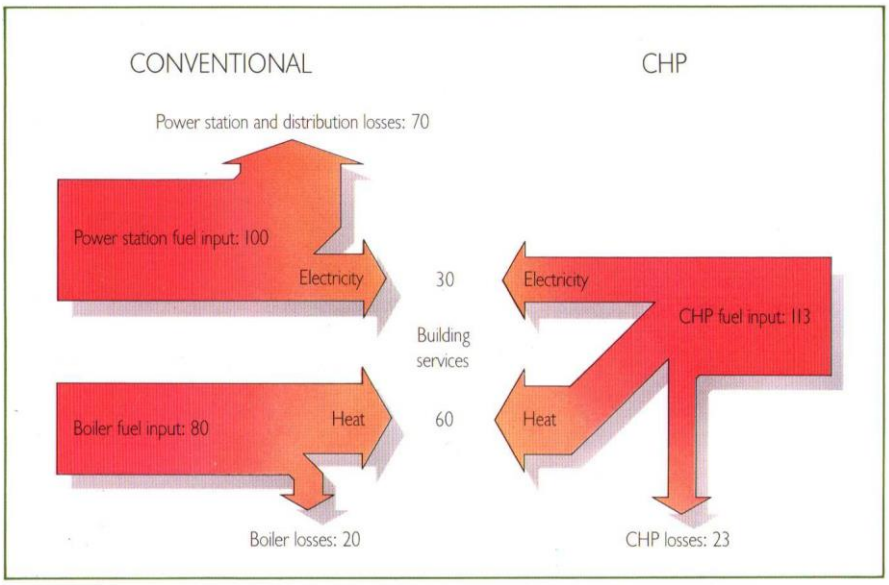
☐ improved insulation in buildings;

☐ more efficient lighting (miniature flourescent bulbs use about a quarter as much electricity as conventional ones);

☐ more efficient motors and appliances (washing machines, fridges and so on);

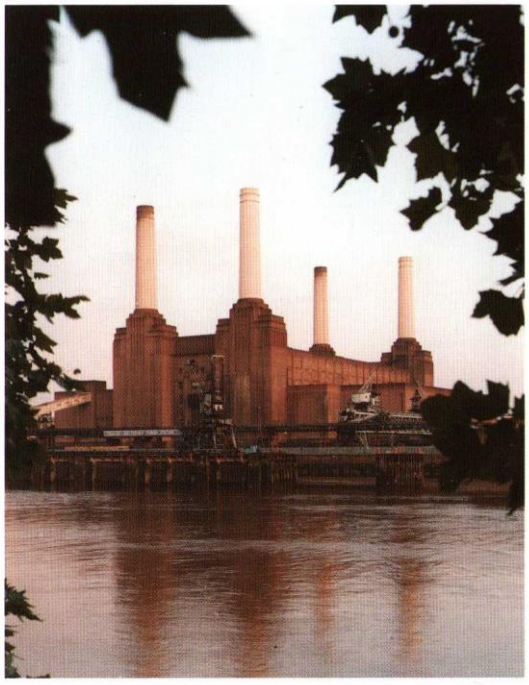
☐ better design of vehicles (we are already well on the way to being able to manufacture 60mpg cars);

Fuel efficient cars are currently being developed



Combined heat and power is much more efficient than conventional electricity generation

Battersea Power Station – combined heat and power is not new



☐ improved control of energy use in buildings and industrial processes;

☐ wider use of combined heat and power (in effect using the waste heat from electricity generation).

The question is how fast can such measures be introduced; and can we leave it to the free market or should governments be more directly involved?

19. A number of international organisations, such as the World Energy Conference and the International Institute for Applied Systems Analysis, have estimated future energy demand. Even their lowest estimates, which take into

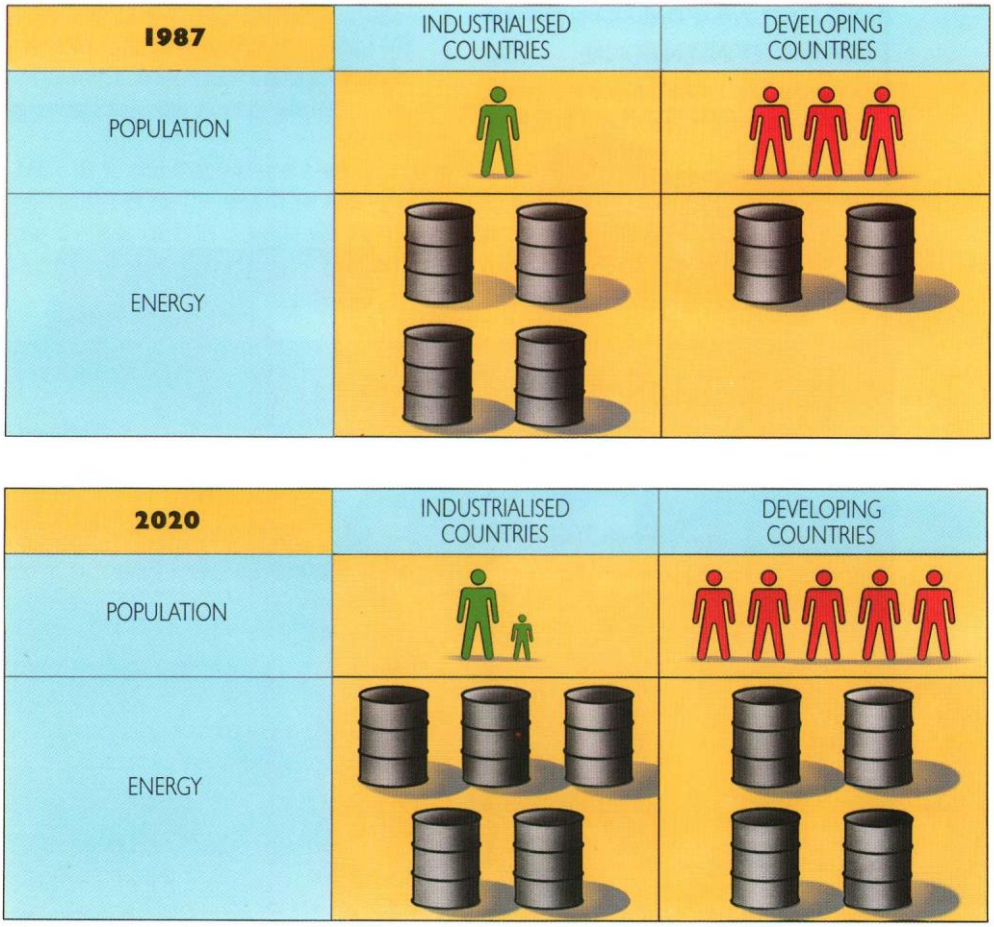


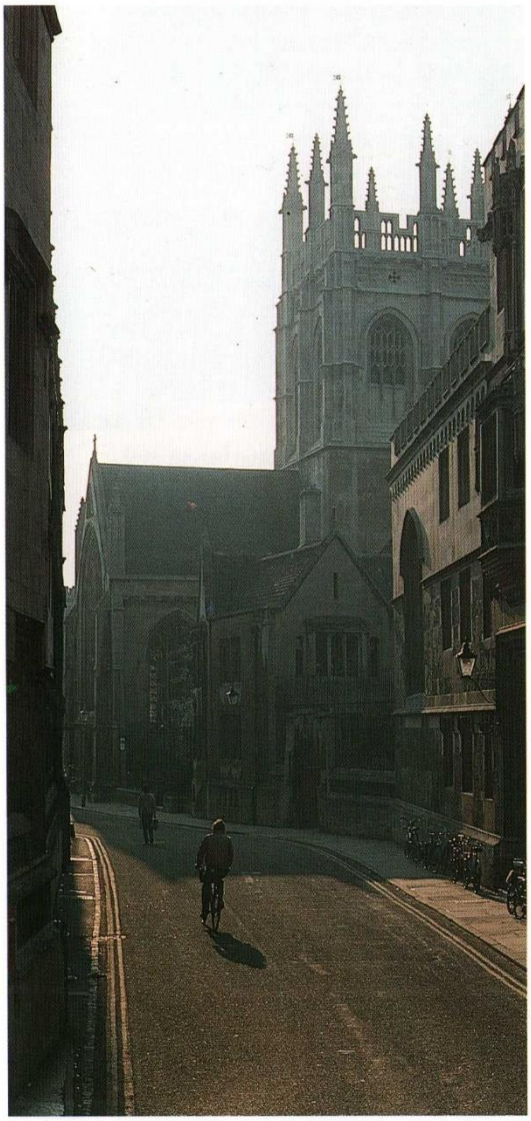
Figure 9. *Growth in population and energy demand 1987–2020*

account major improvements in energy efficiency, show energy use per person rising in both the developed and developing countries. Allowing also for rising world population, all these organisations agree broadly that by the year 2020 the world will be using at least 50% more energy than today (Figure 9).

20. Another international organisation, the World Resources Institute, has argued that even stronger measures must be taken to increase the efficient use of energy. They claim that the technology exists for us to achieve much higher cost-effective energy savings in the developed countries – a goal which if reached would result in a

halving of the energy use per person. In this way they say that energy demand in 2020 could be kept at about the same level as today, even allowing for some increase in use in developing countries. However, this goal could not be brought about easily, largely because:

Merton College, Oxford - parts are 800 years old



☐ for most consumers energy efficiency is not their main interest;

☐ there is no clear and unbiased information available for consumers that shows the economic benefit to them;

☐ each consumer would have to contribute. This would involve a large number of separate small actions and individual decisions;

☐ there would certainly be delays in applying the most cost–effective solutions because of the long life of equipment and, especially, buildings.

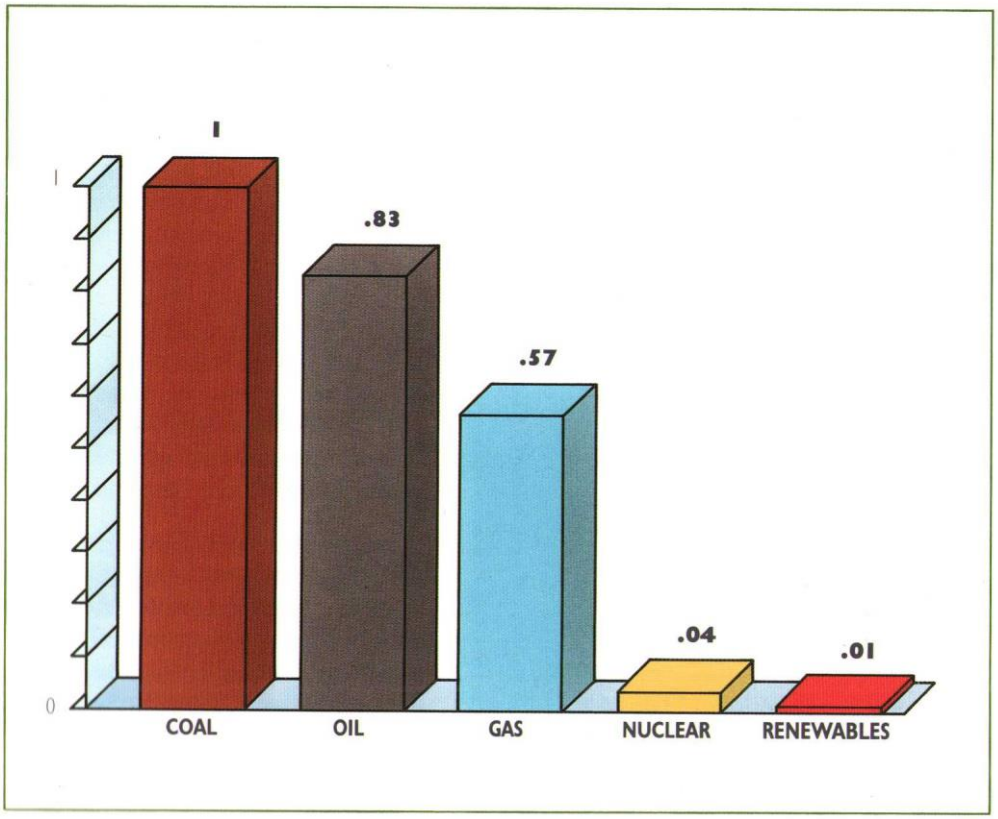
21. In practice it is unlikely that world energy use can be held down to today's level even if every additional effort is made to improve energy efficiency. More improvements may be achieved than had been previously assumed, but in the authors' opinion energy demand will still rise to some extent and by 2020 could well be approaching the 50% minimum increase predicted by the World Energy Conference and others.

22. Thus improved energy efficiency by itself is unlikely to be enough. Unless something is done the quantity of carbon dioxide (and other Greenhouse gases) resulting from energy use will go on rising. Consequently additional means of reducing carbon dioxide emissions must be used.

WHAT OPTIONS ARE AVAILABLE?

23. We could switch to fuels that do not emit as much carbon dioxide. For example, natural gas emits only about 60% as much carbon dioxide as coal for the same energy output (Figure 10), and so there would appear to be immediate benefit in using it in place of coal. This is not the full story however. Factors such as gas leakage, efficiency of energy conversion (for example heat to electricity) and new combustion technologies have to be taken into account. Nevertheless, it is generally accepted that such a fuel substitution would be beneficial. Unfortunately, to have much impact on carbon dioxide emissions the use of gas would have to expand a great deal, and gas supplies are limited even allowing for new natural gas discoveries. Hence this approach is not the final answer, but it could buy valuable time while we introduce other, more Greenhouse–friendly, alternatives.

Figure 10. *Relative CO_2 emissions per unit of electricity*

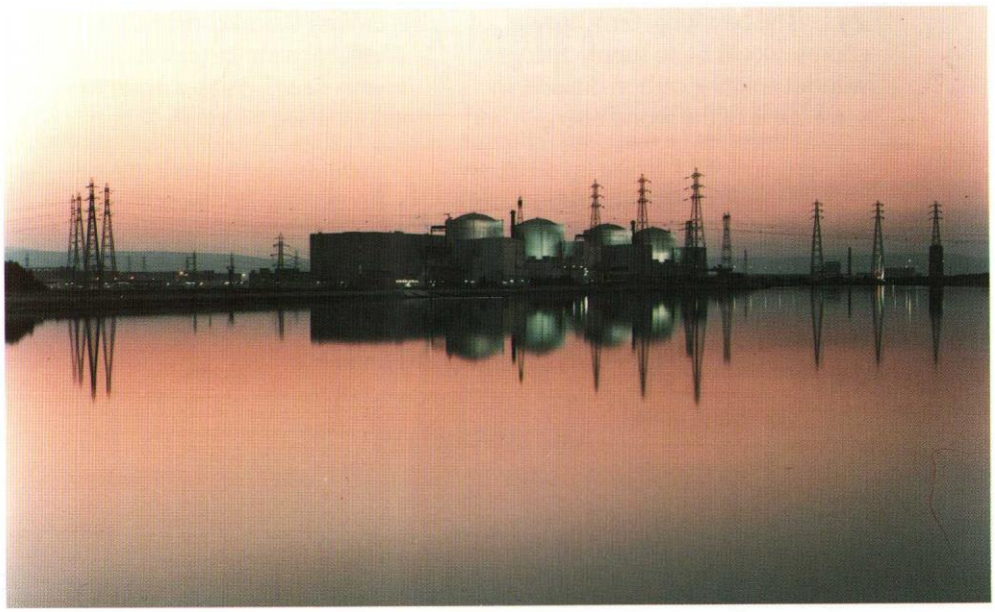


24. The best long-term answer, of course, would be to supply energy without emitting carbon dioxide. In some parts of the world energy from the sun and the Earth's own heat (geothermal) is already making some contribution to heat supplies. In others, crops are grown as energy sources; for example fuelwood in the developing countries. Although carbon dioxide is emitted during use of these crops, provided they are replanted they re-absorb carbon dioxide. However, the application of these technologies alone is unlikely to make more than a small additional contribution to the world's energy needs, particularly in the industrialised countries.

Solar heated building

Woburn Abbey is heated by burning straw

Hot water from geothermal wells, Jonzac, France



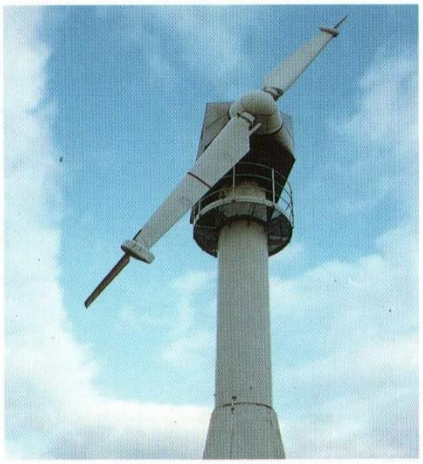
View of Tricastin, Pierrelatte, France: site of four 915MWe Pressurised Water Reactors

25. It is also difficult to foresee major changes in the fuel required for transport purposes in the near future. In Brazil a fuel mix that includes 'gasohol', a fuel derived from a wild sugar cane, is used to power cars, but this is of limited application. Development of more efficient engines, greater use of rail and bus transport and a move to electrification (of rail and even of cars) are some of the long-term ways forward.

26. A more immediate approach to reducing carbon dioxide emissions would be to replace fossil fuel combustion in the electricity sector by alternative energy sources that do not emit carbon dioxide. Alternatives to fossil fuels are already available in this sector. Moreover, electricity is becoming a preferred source of energy in the developed countries where its use is growing more rapidly than overall energy demand. This increase in electricity's share of energy usage is expected to continue and to carry through into the developing countries. Overall, world elecricity demand is predicted to double over the next thirty years or so.

27. There are several ways of generating electricity without emitting carbon dioxide.* Today there are two such technologies in widespread use – hydropower and nuclear power. Together they generate 37% of the world's electricity and save the emission of 3.75 billion tonnes of carbon dioxide each year. This is equivalent to saving around 14% of the energy-CO_2 that would be

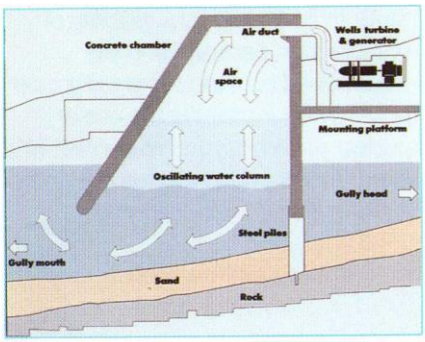
released were all this electricity to be generated using coal. There is scope for expanding hydropower though it tends to be limited by availability of suitable sites, particularly in the industrialised countries. There is greater potential for increasing the use of nuclear power beyond its current 16% share of the world's generated electricity and this is now examined in detail.



3 MW Wind Turbine generator on Orkney

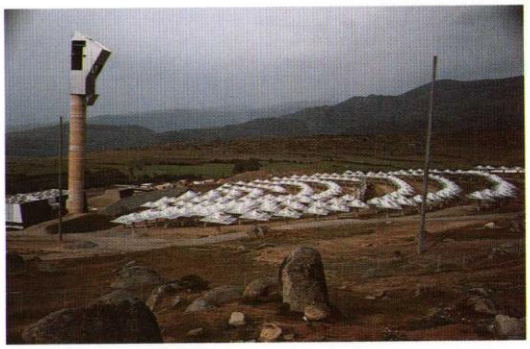
** Many of the sources of energy supply that are said not to emit carbon dioxide are still responsible for small releases to the atmosphere. For example, construction of hydropower stations, nuclear power stations, wind generators, etc. requires energy that involves the release of carbon dioxide. Mining and processing of uranium also require energy. But overall the carbon dioxide "released" by these sources is only a small fraction of that released by burning coal.*

Hydroelectricity provides cheap electricity in many areas but its expansion may be limited by a shortage of suitable sites and by environmental considerations



Schematic of a prototype wave device being constructed on the island of Islay in the Inner Hebrides

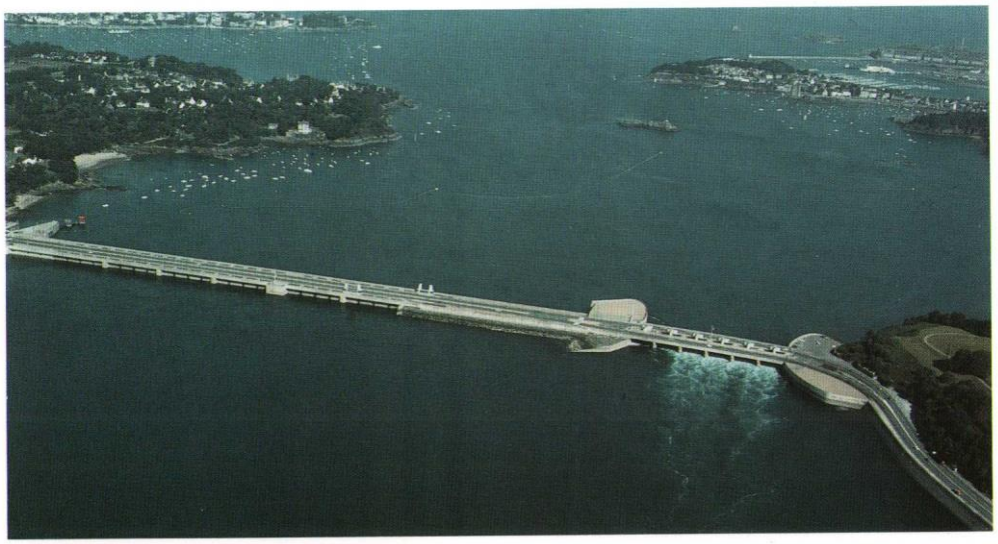
28. It must first be stressed that, in addition to hydropower, there are several other renewable energy sources that can generate electricity. These include the wind, the waves, the tides, the sun and the Earth's own heat (geothermal). However, these technologies are generally at an earlier stage of development and, geothermal apart, they will not provide a continuous supply of electricity. With the possible exception of wind energy, they are more expensive than hydropower and nuclear power.



2 MW Themis Solar Power Station, France

Consequently they are unlikely to make a substantial contribution to world energy demand over the next few decades.

Tidal barrage, Rance Estuary in Brittany, France



What could Nuclear Power do?

IN THE SHORT TERM (TO 2020)

29. Clearly nuclear power would save more carbon dioxide emissions if it displaced more coal and oil for electricity generation. The rapid expansion of nuclear power in France shows what can be done (Figure 11).

30. If nuclear power continues to grow at its present slow rate, it might be generating about a fifth of the world's electricity by 2020. At this level it would be saving around 4 billion tonnes of CO_2, that is 12% of the energy–CO_2

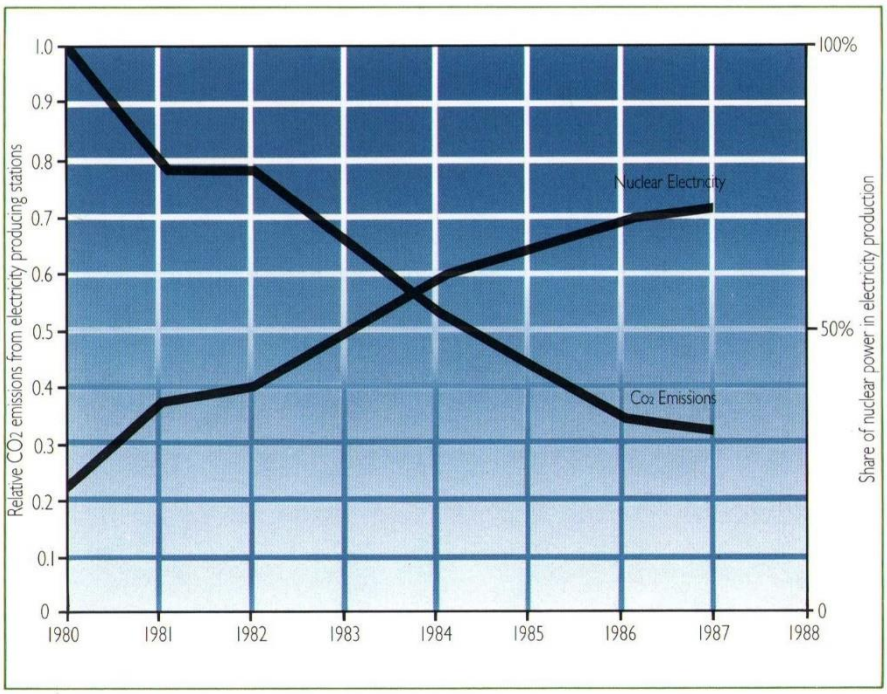


Figure 11. *Production of nuclear electricity and reduction of carbon dioxide in France*

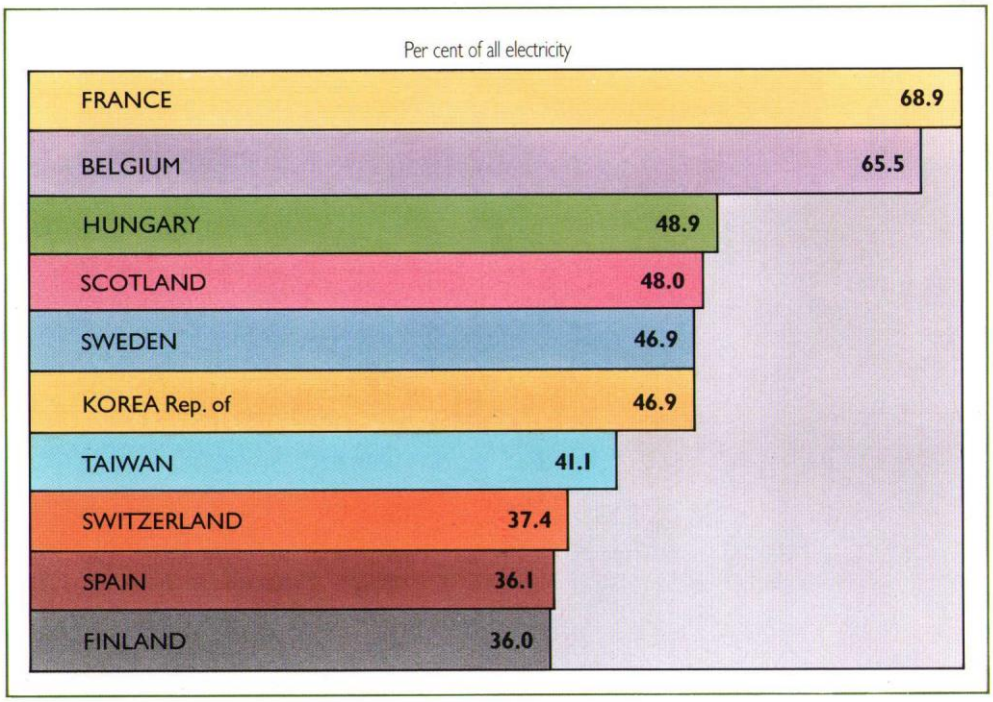
In addition nuclear–generated electricity could displace coal and oil in such industries as steel–making, and could even extend into transport (railway electrification, electrically–powered cars).

that would otherwise be emitted in that year. Even so, energy–CO_2 emissions would still be significantly greater than today. We need to do much better than that. Some experts

believe that total man–made carbon dioxide emissions must be halved from today's levels. Can nuclear power do more?

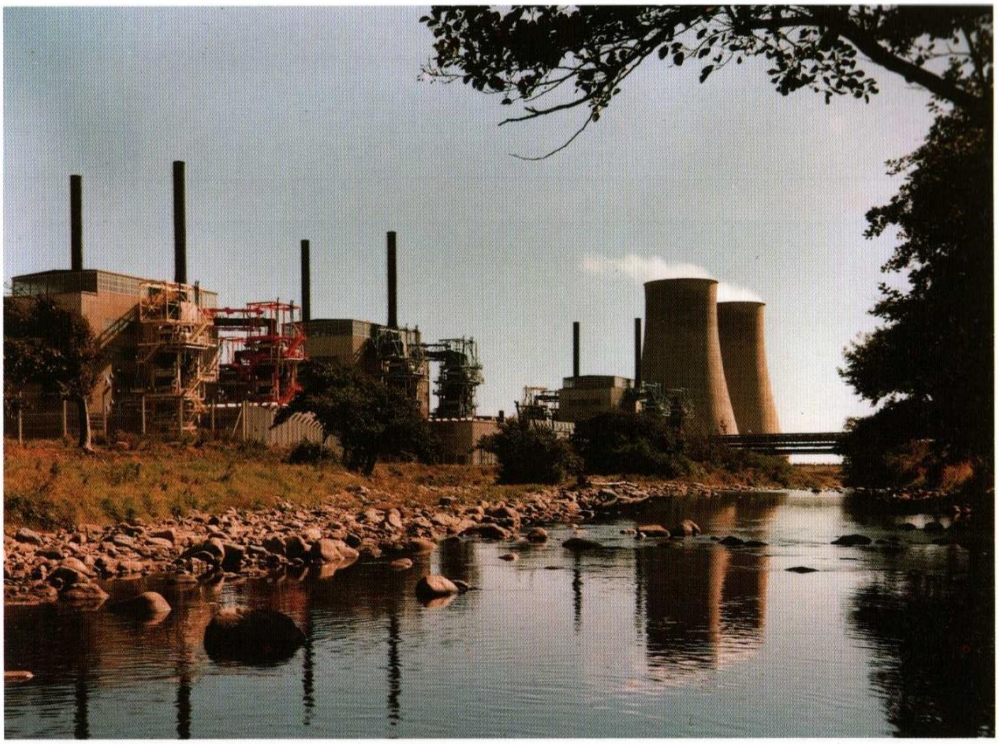
31. If the world's nuclear power programme was pushed hard, nuclear stations could be generating half the world's electricity by 2020 and reducing energy–CO_2 emissions by about 30% of what they would otherwise have been. Since the developing countries are unlikely to be able to install much nuclear power by 2020, it would have to be providing almost two–thirds of the electricity requirements of the developed countries (including the Soviet bloc) by that date. To meet this target the rate of building nuclear plant would have to be high, one large plant commissioned every 6 days. This is by no means impossible: about 70% of France's electricity is generated from nuclear (Figure 12) and they reached that position in 30 years. Such a programme would be expensive but electricity power stations would be required in any case, and it would only be a question of building nuclear stations instead of coal or other fossil–fuelled ones. Moreover, the economics would certainly favour nuclear if fossil–fuelled stations had to include the costs of their polluting emissions.

Figure 12. *The ten countries with the highest nuclear share of generation in 1987*



32. Even this ambitious nuclear programme – associated with major energy efficiency measures – would not meet the target reduction set for carbon dioxide emissions in the energy sector. But it would have gone some way to keeping emissions below today's levels. Nevertheless, yet more would have to be done if the high target reduction of 50% below today's levels, set by the Toronto international conference in 1988, were to be met. Switching to gas in place of coal and oil wherever possible would be of further help – but as has already been pointed out, gas resources are limited. The "renewable" sources of energy (wind, wave, tidal power) offer additional benefits, although these are likely to be limited also in the short-term.

33. Waste heat from nuclear power stations, like any other, can be used in Combined Heat and Power schemes. This is already done to a limited extent, for example in Russia, and would cut down further on fossil fuel use (saving even more carbon dioxide). However, siting nuclear power stations close to population centres will prove difficult until the general public appreciates that nuclear power is safe.



Calder Hall – the world's first nuclear combined heat and power station

IN THE LONG TERM

34. Looking still further ahead, by the end of the next century world population is expected to be about ten billion, double today's level (Figure 13). It must be expected that living standards for many people in the developing countries will be much higher than they are now. Consequently, even if energy is used very efficiently, the world could be expected to need twice as much as today. By then natural gas will have run out, oil will be in short supply and coal will be left as the only significant fossil fuel. It must be assumed that use of coal will be severely limited by the continuing need to minimise carbon dioxide emissions. Under these circumstances it will be essential to rely a great deal on power sources which emit no carbon dioxide – nuclear power, hydropower and the other 'renewables': indeed these will probably provide the world's major energy sources of the future.

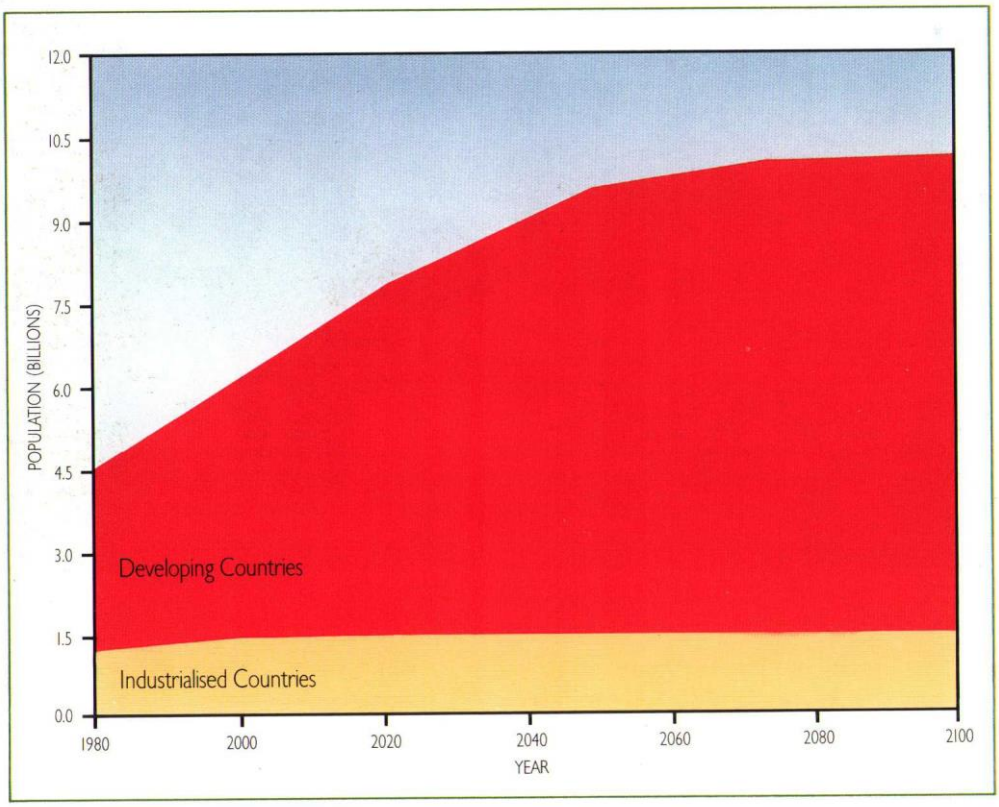


Figure 13. *Future world population*

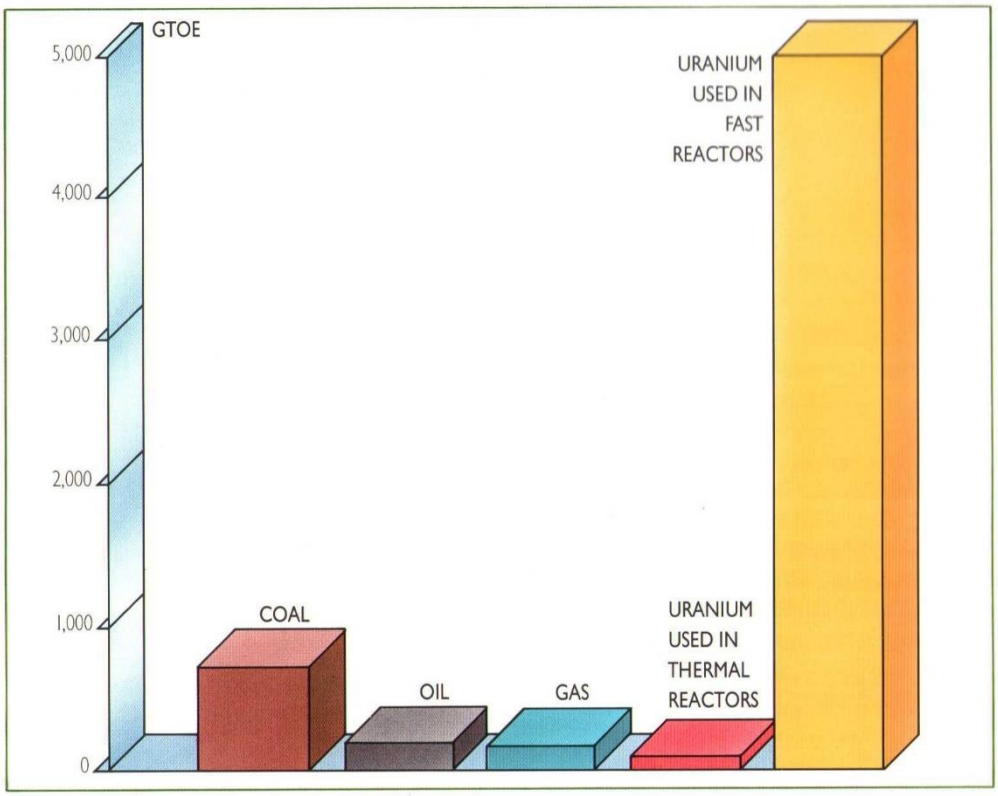


Figure 14. *World fuel resourses*

35. We must, of course, ask ourselves how long would our uranium resources last if we were to use nuclear power at this rate? Used in the type of reactors now in operation, the world's uranium supplies that are recoverable at a reasonable cost would be unlikely to last more than about 50 years. This is because these "thermal" reactors are only able to use a small fraction of the energy available in uranium. However, the next generation of reactor, the "fast" reactor, will be able to use virtually all the energy in the uranium and would thus increase the energy resource of the world's uranium by at least sixty times (Figure 14). Indeed the fast reactor could use uranium that would be discarded as waste by thermal reactors. The UK alone already has stocks of this waste uranium (25,000 tonnes) that, if used through a fast reactor, would provide the energy equivalent of all the UK's economically-recoverable coal resources (about 45,000 million tonnes). Fast reactors are expected to be at the stage of commercial introduction during the first or second decade of the next century.

What can we conclude?

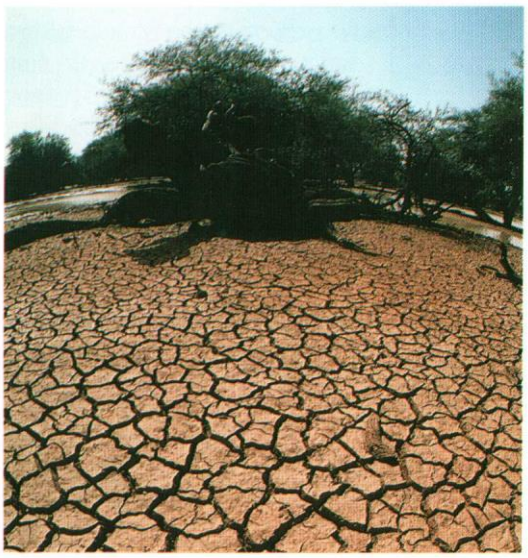
36. It is widely expected that Greenhouse gases now being pumped into the atmosphere will bring about higher temperatures and other changes in climate, such as in rainfall patterns and in an increase in storms. These changes could have serious consequences throughout the world as a result of loss of low-lying land, shifts in food-growing areas, major movements of population, etc.

37. If the changes caused by the Greenhouse Effect should turn out to be as serious as many people think, emissions of all Greenhouse gases would have to be minimised. The energy sector is a major source of Greenhouse gases (mainly carbon dioxide) that, by 2020, could be contributing about half of global warming emissions. Its contribution could be reduced by:

☐ applying stringent energy efficiency measures both to energy conversion (e.g. electricity generation) and the way we use energy. This is the first vital step but alone it is not enough.

☐ using natural gas, which emits less carbon dioxide, in place of coal and oil. This is useful but is at best an interim measure;

☐ using power sources which emit no carbon dioxide*: hydropower, nuclear power and the "renewables".



38. The use of nuclear power could be readily expanded. By 2020 it could be reducing energy-CO_2 emissions by 30% of what they would otherwise have been, effectively reducing global warming by 15%. In the longer term it offers much deeper cuts in Greenhouse gas emissions from energy.

*See footnote on page 23

Acknowledgements

Photographs

6 TROPIX Photographic Library.

7, 9, 10, 11, 14 Associated Press.

7, 21, 24 Topham Picture Library.

8, 13, 30 Science Photo Library.

10 Worldwide Fund For Nature.

11 The Hulton Picture Company.

16 V.A.G. (United Kingdom) Limited.

17, 19, 22, 23, 24 National Power.

19 Chris Andrews.

All others are UKAEA.

Figures

2 A M Soloman et al, The Global Cycle of Carbon, USDOE publication DOE/ER 0293, December 1985.

3 Climatic Research Unit, University of East Anglia and the United Kingdom Meteorological Office.

4 Bradley RS, and others, Precipitation fluctuations over Northern Hemisphere Land Areas since the mid–19th century, Science 237, 171–175, 1987.

5 Professor TML Wigley, Climatic Research Unit, University of East Anglia.

7 Derived from several sources – details are given in Annex 2, Table A 2.3 of Nuclear Power and The Greenhouse Effect by D M Donaldson and H G Tolland. A technical report produced by the UKAEA.

12 World Nuclear Industry Handbook 1990, Nuclear Engineering International.

13 United Nations.

All others are UKAEA.

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