

RECORD OF A PRESENTATION ON ACID DEPOSITION GIVEN AT
CHEQUERS ON SUNDAY 27 MAY 1984

Present:

The Prime Minister
The Secretary of State for the Environment
The Rt. Hon. Kenneth Baker, MP, Minister of State, DTI,
The Hon. William Waldegrave, MP, PUSS, HM Treasury
The Earl of Avon, PUSS, Department of Energy
Mr. David Pascall, No. 10 Policy Unit
Sir Walter Marshall, Chairman, CEGB
Dr. Peter Chester, Central Electricity Research Laboratory
Sir John Mason, Royal Society
Sir Hermann Bondi, NERC
Dr. Martin Holdgate, Department of the Environment
Dr. Robin Nicholson, Cabinet Office

The presentation had been arranged to give Ministers a fuller appreciation of the scientific background to forthcoming policy decisions on acid rain.

Introducing the presentation, Dr. Nicholson said that it had two objectives: first to present the scientific evidence; and secondly to describe the state of the art and possible developments in abatement technology.

Sources of Emissions

Dr. Nicholson then described the principal sources of emissions associated with acid deposition. In the Northern Hemisphere, 90% of the sulphur dioxide in the atmosphere was man-made. The proportion was much less in the Southern Hemisphere. In the United Kingdom, 65% of sulphur dioxide emissions came from power stations. Around 50% of atmospheric NOx was man-made, and of this amount nearly half

came from power stations, and another 34% from motor vehicles. Both sulphur dioxide and NOx could oxidise to give acid deposition. The other important ingredient was hydrocarbon, from unburnt motor fuels, spillages, leaks etc. The hydrocarbons were not a serious pollutant in themselves, but they played an important secondary role eg in production of ozone which could damage leaves.

Sulphur dioxide emissions in the UK had peaked in 1970, but declined substantially since then. Total European emissions had however increased dramatically over the same period, primarily because of developments in Eastern Europe. As a result of these two trends, the United Kingdom now accounted for 11% of European sulphur dioxide emissions, as opposed to 25% in 1950. There had been a steady rise in NOx emissions from motor vehicles, as the number on the roads had increased.

There were three basic approaches to abatement. First there was prevention of pollution at source - for example, the use of smokeless fuels, and lead-free petrol. Secondly, pollutants could be removed at or near the source - for example dust removers in industrial processes. Thirdly, it was sometimes possible to counter the ecological effects of particular pollutants - for example by liming acid lakes.

Chemical Changes in the Atmosphere

Sir John Mason described the complicated sequence of events which lay between emission of a pollutant and acid deposition. Gaseous sulphur dioxide and NOx from United Kingdom power stations could undergo a journey covering many miles and lasting many hours. Prediction of the consequences in terms of acid deposition was complex. It depended both on physical factors such as wind speed and direction, the stability of the atmosphere, and the presence of clouds or sunshine; and also on a complex chain of

chemical reactions, which themselves required atmospheric oxidising agents generated by ultra-violet light. There was thus no direct connection between emissions and deposition, as was illustrated by the fact that depositions were at a maximum in summer when emissions were at a minimum.

Moreover, there was no direct connection between acid deposition and damage to forests or lakes. Other speakers would explore this area in more detail. But it was important to note that external influences (eg the presence or absence of fertilisers) could be just as important as acid deposition.

Turning to the distribution of sulphurous depositions in Europe, Sir John Mason said that 80% of sulphur falling in the UK was home-made. But UK emissions played a relatively small role in the problems of Scandinavia - for example 6% of sulphur falling in Sweden came from UK sources. In the United Kingdom rain was acid everywhere, with an average pH of between 4.2 and 4.5 compared with 5.6 for uncontaminated rain. Such evidence as there was suggested that the degree of acidity had been roughly constant between 1954 and 1976, although it might now be increasing slightly. The Norwegians claimed that the average pH value of rain had moved from 4.5 to 4 between 1955 and 1970, but the evidence for this was questionable.

Summing up, Sir John Mason said that long term changes in acidity seemed less important than short term episodes. Heavy acid deposition occurred on perhaps 10 days each year. There was good evidence that the mortality of fish in Scandinavian lakes was related to heavy rain after a long dry spell, or to snow melt, since both these circumstances produced a surge of acid. This suggested that strategies could be developed to prevent the worst effects of acid deposition if periods of heavy rainfall or sudden temperature rise could be predicted. For example, power

stations might change over to low sulphur fuels at a week's notice.

Lakes and Streams

Sir Hermann Bondi described the effects of acid depositions on lakes and streams. The process started on land, and in some circumstances the acidity of rain could increase markedly between the time it fell and the time it reached a stream or lake. For example, water running down the trunk of a conifer leached out acidic substances from the tree itself and became more acidic. The phenomenon was less apparent with deciduous trees. Forest management thus assumed critical importance. If trees were felled selectively, rather than in large areas, less acid was released. A still more effective technique was whole tree removal, which avoided the acidic decomposition of brushwood. There was evidence also that the disturbance of moorland could produce a pulse of acidity in streams. In Great Britain, there was evidence of significant damage to fresh water mainly in the North East and in certain parts of Scotland. These changes seemed to be associated with large scale changes in land use.

Forest Damage

Dr. Holdgate spoke first about the history of sulphur dioxide pollution. Originally, the problem had been associated with acute damage near industrial sites, but these had become less significant since the clean air policy had taken effect. Concern revived in 1972, when the Swedes reported forest damage associated with acid rain. However, their simplistic analysis had not stood up to technical criticism. Very recently, however, there were reports from Germany of a new kind of forest damage, and these lay behind the present international concern.

Damage had been observed first in silver fir trees, and later in other types. Conifers exhibited loss of needles, stunted growth, the thinning of tree tops, and increased infection by pests and funguses. In 1982, the German Government had estimated that 8% of their forests were badly affected. In 1983 after an exceptionally dry summer, the estimate was 34%, although 25% within this represented only slight damage. The effects were worst in Bavaria and the Black Forest. Fifty per cent of the silver fir population showed signs of damage, although this type of tree represented only 2% of German forests. However, 40% of spruce trees were also said to be damaged, and spruce represented 40% of the forest total. Whilst there was room for argument over the figures, it seemed clear that forest damage was a genuine phenomenon which affected large areas of Central Europe.

Dr. Holdgate then summarised current understanding of the causes of forest damage. The effect was correlated with altitude, drought and cold, and it particularly affected tall trees at the edge of forests. It seemed that factors such as soil type, cultivation techniques, and the presence of insects and funguses were significant. Pollution by gaseous sulphur dioxide was probably significant only in the remaining "hot spots" near industrial plants. There was a superficial correlation between wet acid deposition and forest damage, but the effect could not be reproduced in the laboratory. The favoured hypothesis was that both wet acid deposition and the presence of other "poisons" were necessary. Thus it appeared that high levels of ozone were a major factor in the German forest decline.

It seemed possible that ozone, and perhaps also sulphur dioxide itself, damaged the leaf cells, leaving them vulnerable through rainwater removing essential magnesium and calcium. The removal was aided if the rain itself was

acidic. As a result of the mineral loss, the roots of the tree were stressed by trying to make up the loss, and this weakening could be aggravated by cold and drought. It was argued by some authorities that very high levels of acidity could lead to the release of aluminium in the soil, which poisoned the root.

Summing up his contribution, Dr. Holdgate said that sulphur dioxide alone was probably not the most sensitive variable in the process of forest damage. It was at least as important to control emissions of NOx and hydrocarbons, which led to the production of ozone.

Abatement Technologies for Power Stations

Dr. Peter Chester discussed the application of abatement technology at UK power stations. He emphasised that the effect of any particular reduction in emissions was impossible to predict. One reason for this was that the supply of photo-chemical oxidants from hydrocarbons might well be the limiting factor.

Possible techniques for abating sulphur dioxide emissions included the removal of sulphur from coal; the injection of limestone (although this would be difficult to apply in the UK, because of the high flame temperature employed); and flue gas desulphurisation. The latter technique could remove about 90% of the sulphur dioxide in flue gas, and had been operated successfully elsewhere in the world. However, it produced calcium chloride, which was difficult to dispose of, and it was extremely costly to retro-fit and only slightly less costly if incorporated in a newly built power station. The capital cost would be in the region of £135-£160 million per 2000 MW power station. In addition each such station would suffer a reduction in output of between 50 and 75 MW, and there would be an efficiency loss of 3-4%. These costs were equivalent to an

/ Dr. Chester

increase of £8 per tonne in the price of coal. The Prime Minister commented that costs of this order were quite prohibitive.

Dr. Chester continued that, because of the high cost of flue gas desulphurisation, the CEGB was exploring alternative technologies. The most promising was fluidised bed combustion - this would be cheaper than FGD, and involve a smaller loss of energy, but it would not be available until about the year 2000. As for emissions of NO_x, the preferred route would be to keep air away from the fuel for as long as possible by altering the dimensions of the flame in burners. But there was a risk of greater corrosion, which meant that the cost of the 40% reduction by 1995 which the EEC was seeking could be substantial. The Japanese had adopted a different approach which involved removing NO_x from flue gas. But equipment of this sort was much more expensive and was difficult to fit in addition to flue gas desulphurisation.

In conclusion, Dr. Chester emphasised the high costs involved in rapid reductions of SO₂ and NO_x emissions, and the uncertain result in terms of reduced damage to forests and to fresh water. The figures he had quoted were for the CEGB only. It was important to remember that the rest of industry would also face additional burdens.

Abatement Technologies for Vehicles

Dr. Nicholson said that vehicles were as important a source of NO_x and hydrocarbon pollution as power stations and one of the main sources of hydrocarbons. The Americans had tackled the problem by requiring the fitting of three-way catalyts. These were effective when new, but tended to deteriorate rapidly in use. Indeed, some drivers simply removed them. They were expensive to instal (£600

per car) and maintain, and carried a significant penalty in terms of reduced fuel economy (a loss of 10%). Overall, the technology of the three-way catalyst was not highly regarded, although it was fashionable in some quarters.

The preferred solution to vehicle emission control from the UK's point of view was undoubtedly the lean-burn engine. This involved increasing the proportion of air to fuel in the cylinder. Lean-burn technology was favoured by BL and by Ford of Europe, by the French motor manufacturers and by the smaller German manufacturers. It cost very much less per vehicle than the fitting of catalysts (about £100), involved no maintenance costs, and was more resilient. Lean-burn engines could be adjusted either to minimise emissions, or to maximise fuel economy but even with the former, overall fuel economy was not adversely affected.

Concluding, Dr. Nicholson said that improvements in emissions from vehicles were only part of the story for hydrocarbons. Pollution from spillage and leakage of fuel should not be overlooked.

8 June 1984



cc WO
 Dr. Nicholson
 FCO
 DTRANS
 CS, HMT
 Kenneth Baker's Office, DTI
 CO
 MAFF
 SO
 8 June 1984

ce MATTER . 10 DOWNING STREET

From the Private Secretary

Dear John,

Acid Rain

Further to my letter of 30 May, I now enclose a record of the presentation on the subject of acid deposition which was held at Chequers on 27 May.

Also enclosed are papers tabled at the presentation by Sir John Mason, Dr. Martin Holdgate, and the CEGB.

I am sending copies of this letter and the enclosures to the recipients of my letter of 30 May.

*Yours ever,
 David*

David Barclay

John Ballard Esq
 Department of the Environment.



filed ck

10 DOWNING STREET

From the Private Secretary

DR. NICHOLSON
CABINET OFFICE

Acid Rain Presentation

BF7
I enclose a draft record of the scientific presentation on acid deposition which was given at Chequers on Sunday 27 May. I should welcome comments and any necessary amendments.

We discussed the possibility that the record should be combined with other material to form a more comprehensive document. Perhaps, when you have had a chance to consider the draft, we could have a further word about this.

DB

1 June 1984

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DRAFT

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There were three basic approaches to abatement. First there was prevention at source - for example, the use of smokeless fuels, and lead-free petrol. Secondly, pollutants could be removed at or near the source - for example dust removers in industrial processes. Thirdly, it was sometimes possible to counter the ecological effects of particular pollutants - for example by liming acid lakes.

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Concluding, Dr. Nicholson said that improvements in emissions from vehicles were only part of the story. Pollution from spillage and leakage of fuel should not be overlooked.

1 June 1984

VSCABW

SOME NOTES ON THE AERIAL TRANSPORT, CHEMICAL TRANSFORMATIONS
AND DEPOSITION OF ACID POLLUTANTS.

By B.J.Mason

1. The Complexity of the Problem.

The present state of scientific knowledge does not permit us to predict, in quantitative terms, how a given reduction in the emissions of SO₂ and NO_x will affect the acidification of streams and lakes, the mortality of fresh-water fish or the die-back of trees for the following reasons:

- (i) There is no simple, linear relationship between the emission of SO₂ and NO_x and the quantity of acid deposited at distances remote from the source. This is because the deposition patterns are determined in a complex manner by the meteorological factors governing the movement and dispersion of the emitted plumes and by the complex atmospheric chemistry involved in converting the SO₂ and NO_x gases into acids. For example, rainwater tends to be most acid in summer when emissions from power stations are at a minimum.
- (ii) There is no simple relationship between the acidity and chemical composition of rain/snow reaching the ground and the acidity and chemical composition of streams and lakes because the chemistry of rainwater may be profoundly modified as it percolates through the soil and interacts with the bedrock, soil and vegetation. In particular acid water may be largely neutralized by base minerals such as Ca in the soil or may be further acidified by the indirect effects of vegetation, trees and fertilisers.

In other words, the acidification of lakes depends upon the geology and soil chemistry besides the acid deposition from the atmosphere.
- (iii) There is no simple relationship between the acidity of streams and lakes and fish mortality because this also depends on the species, size, age and genetic origin of the fish and how their food chains are affected. Moreover it appears that fish, (especially the eggs and fry), are mainly killed by Al leached out from the soil rather than by acid stress. On the other hand, Al is largely de-toxified in the presence of calcium or organic acids.
- (iv) The worst effects of acid deposition tend to be produced in short intense episodes rather than by long-term gradual increases. Thus a high proportion of the total annual acid deposition occurs on only a few days of heavy rain in both the UK and Scandinavia. Moreover high mortalities of fish eggs and fry are produced mainly by high acid surges in the rivers during the first rains following a dry spell. This has important implications for the control and alleviation of emissions.

- (v) It is also important to remember that if a 30% reduction in emissions led to a 30% reduction in the acidity of the rainfall and surface waters, this would correspond to an increase in pH of only 0.15 unit. Changes of this magnitude would hardly be detectable because the uncertainties in pH measurement are larger than this.

A 30% change in the sulphate content of rain/lake water should be detectable, but only if the measurements were averaged over a long period because of the large day to day variations.

We now describe, in a little more detail, what happens to the SO₂ and NO_x gases from the time they leave the chimney stack until they are deposited as acidic gases, particles or raindrops on the ground.

2. Emissions

Emissions of SO₂ from the UK increased from 1.5 million tonnes of S in 1900 to reach a peak of 3.2 Mt in 1965 since when they have declined by about 40% to about 2.0 Mt in 1983.

The emissions of NO_x, on the other hand, have continued to increase from 0.25 Mt in 1900 to about 0.62 Mt in 1980. However, this latter figure may be an underestimate, because measured concentrations of NO_x in city centres such as Glasgow are at least 5 times those of SO₂.

By contrast, total emissions of SO₂ in Europe (excluding the USSR) have risen continuously from 10 Mt of S in 1950 to 20 Mt in 1980.

3. Dispersion and Deposition

Once the plume emerges from the chimney it travels roughly with the wind and is spread laterally and vertically by atmospheric turbulence, whilst maintaining its identity over hundreds of miles.

Acid products falling from the plume to the ground at short distances from the source are usually in the form of gases and small particles. This so-called dry deposition accounts for about 2/3 of the total deposition in England.

As the plume travels greater distances, say over the N.Sea, it is carried to greater heights (several thousands of feet) and stands a greater chance of entering a cloud system. Here the SO₂ and NO_x are converted into H₂SO₄ and HNO₃ much more rapidly than in clear air and are rapidly brought to the ground as wet deposition in rain or snow. The heaviest deposits, therefore, tend to occur in areas of heavy rainfall i.e. in the mountainous areas of Scotland, Wales, N.W. England and in S.W.Norway.

About 80% of the total acid deposition in the UK originates from UK sources, only about 12% coming from continental Europe.

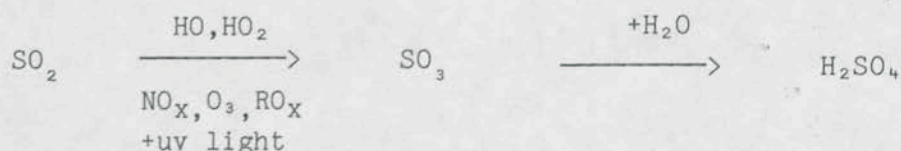
The UK contributes about 15% to the sulphate deposition of Norway and about 7% to that of Sweden. Sweden receives at least as much

from Denmark and from FRG, 3 times as much from the Eastern bloc and contributes 5 times as much herself. Norway receives about as much from Western Europe as from the UK and rather more from the Eastern bloc. It would obviously be pointless to reduce UK emission by 30% or even 60% unless the rest of Europe, including the Eastern block, did the same.

4. Chemical Conversion of SO₂ and NO_x into Acids.

SO₂ is converted to sulphuric acid and NO_x to nitric acid in the gas phase producing acidic gases and small particles which are deposited on the soil and vegetation as dry deposition and also, and more rapidly, in the liquid phase, in cloud and raindrops.

Conversion in the gaseous phase occurs in stages involving oxidizing radicals such as HO and HO₂ which are derived from NO_x, O₃ and unburnt hydrocarbons viz:

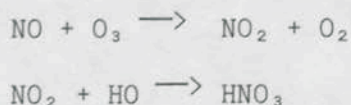


The conversion rate is about 2% per hour on a bright summer's day when about 20% of the SO₂ might be converted during the 24 hours taken for the plume to cross the N.Sea.

In the winter-time the conversion rate is probably only ~ 0.1% per hour, being limited by the lack of oxidants, which require ultra-violet light for their production.

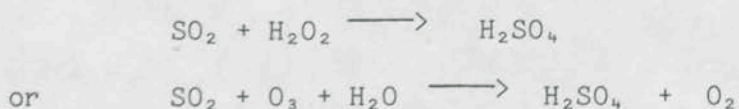
The unconverted SO₂ will gradually be dispersed through the atmosphere and contribute to the general global background.

NO is converted in the gaseous phase to nitric acid with the aid of ozone (O₃) and HO viz:



Complete conversion is likely to occur during a 24 hour crossing of the N.Sea in summer, but only about 25% might be converted on a winter's day.

If the plume enters a cloud layer, the SO₂ is rapidly adsorbed by the cloud droplets and conversion then occurs rapidly in the liquid phase by the reactions:



both involving oxidants which we derived photochemically from NO_x.

Theory indicates that these processes should lead to 100% conversion per hour in summer, and about 20% per hour in winter, unless this is limited by an unusually low concentration of oxidants.

Measurements by the Met. Office aircraft following a plume indicate conversion rates of at least 25% per hour in summer. Nitric acid is also formed in cloud and raindrops, but the rates of conversion have not been studied.

The important point to note is that the rate of formation and deposition of acid is largely determined by the availability of oxidants, which are formed by the photolysis of NO_x and unburnt hydrocarbons. Only a fraction of the SO_2 crossing the N. Sea is converted to acid and reaches the ground. In order to reduce this fraction, it may be more effective to limit the NO_x and unburnt hydrocarbons rather than concentrate solely on the reduction of SO_2 emissions. The fact that the acidity and sulphate concentrations of rainwater tend to be a maximum in summer when the emissions are a minimum may well be due to the greatly enhanced production of oxidants in strong sunlight.

5. Role of Acid Deposition and ozone on die-back of Trees.

Reduction of NO_x emissions and therefore of ozone may also be more important in connection with the die-back of trees reported to be serious in Germany. German scientists are coming round to the view that die-back results mainly from damage to leaves by atmospheric pollutants rather than damage to the roots by the direct or indirect influence of acid rain on the soil.

The greatest damage is observed to spruce and firs growing downwind of highly industrialized regions and in areas where air pollution builds up in stagnant air beneath persistent inversions in the summer time.

Ozone is thought to be the main culprit causing the leaves to fall off even in the green state. It may be that the efficient capture of highly acidic cloud and droplets by the long, thin needles is a contributory factor in that the acid may degrade the wax cuticle and thereby allow ozone easier access to the leaf tissues. The acid also probably leaches out Mg and Ca from the leaves which may die from Mg deficiency.

The damage may also have been accelerated by lack of water during the very dry summers of 1976 and 1981 causing a general deterioration in the health of the trees and making them more vulnerable to later losses of leaves and nutrients.

In any case, if high ozone concentrations are a major factor in tree damage this puts a premium on the reduction of NO_x from automobiles as well as from industrial plants.

6. The Acidity of Precipitation.

In the UK rainfall is acidic almost everywhere with annual mean values of pH ranging from 4.5 to 4.2 compared with 5.6 for uncontaminated rain. In general, rainfall in the UK is just as acidic as that in Norway and Sweden.

There is no convincing evidence that the acidity of UK rain has changed significantly in recent decades. This is probably because the greater emissions since 1950 have been largely offset by using

hot plumes from tall stacks. One of the few reliable long-term records from Cumbria shows that the mean annual value of pH remained constant at 4.4 between 1954 and 1976. A careful record for Loch Ard showed no change between 1973 and 1979. However recent sound measurements at Pitlochry are the first to indicate a drop in acidity of rainfall between 1979 and 1983 in line with reduced emissions of SO₂. Elsewhere in the UK, the measurements are not sufficiently reliable to establish a long-term trend. Scandinavian scientists have claimed that the acidity of rain over much of N.W.Europe increased (pH4.5→4.0) from 1955 to 1970, but a CEEB analysis shows that only 29/120 stations showed a fall in pH, 5 showed an increase, and that some of the reported falls, which showed a step change, were probably due to a change in measuring technique.

Rainfall in remote parts of the world is quite acid. For example, annual average values of pH of between 4.3 and 4.9 are reported from Bermuda, Hawaii and Amsterdam Island in the Southern Indian Ocean.

7. Changes in Acidity of Lakes.

Both direct measurements and proxy measurements (e.g. fossil diatom analysis of lake sediments) give conflicting results.

In the UK

Diatom analysis of lake sediments in Galloway indicate gradual acidification since 1850 with a tendency to acceleration in recent decades. It does not appear possible to ascribe these trends to afforestation or changes in land use.

On the other hand, the FBA (Windermere) long-term, careful measurements indicate no significant change of pH in biologically stable lakes in Cumbria over the last 50 years. Biologically active lakes become very alkaline in summer (pH~ 10) due to consumption of CO₂ by phytoplankton during photosynthesis.

In Norway.

Measurements on 87 lakes in S. Norway indicated that the median pH values fall from 6.4 to 5.7 (nine of the lakes showing a drop of 1.25 units) between 1923-49 and the 1970s.

However, the early measurements are very suspect. An independent survey of 50 lakes in S.E.Norway indicated that, in 27 of the lakes with low Ca content, the pH fell from 6.6 to 6.3 between the 1950s and 1970s. Diatom analysis for a few lakes indicated a drop of 0.5 unit during recent decades, but one lake on the W.Coast seems to have undergone no change over the last 250 years

More accurate, representative and standardized measurements of pH and chemical composition of rain and surface waters will be required to monitor changes and to establish the response to changes in emissions. This is being given high priority by the Royal Society/Swedish Academy/Norwegian Academy joint programme, but it will be difficult to follow such changes in Sweden, where a very high proportion of the lakes are now being limed and there are few control lakes to allow assessment of long-term effects.

THE EFFECT OF ACID DEPOSITION ON FORESTS

I am going to turn my title round. I am going to talk about the observed changes in certain forests first, and the possible causes, including acid deposition second. Finally I plan to say a little about the factors that are likely to be most significant if it is decided that the changes in the forests need to be stopped or reversed. I am not going to talk about crops or stonework although the Royal Commission on Environmental Pollution has commented that present concentrations of air pollutants could reduce yields of some crops in Britain, and the Select Committee on the Environment is reported to have been greatly impressed during their visit to Germany with the evidence of damage to historic monuments.

So: first, a short history of the pattern of damage.

The death of conifer forests, and the failure of plantations, close to industrial centres in Germany, the South Pennines, and around Sudbury in Ontario, have been well documented and related to acute smoke and sulphur dioxide pollution (FRG, 1984: Lines, 1984: Hutchinson,). Clean Air policies have progressively cured this problem in Europe over recent decades.

In 1972 the Swedish Government, in a report to the Stockholm Conference, alleged that acidity, deposited in their country after long range transport from elsewhere in Europe, was damaging their forests as well as their lakes and rivers. This allegation did not stand up to critical examination by specialists and was largely discounted.

The recent renewal of concern dates from the reports of a 'new kind of forest damage' in Germany, starting in the mid-1970s and getting worse during the past 4 years. This damage was first seen in silver fir, and then in spruce: some damage to pine, beech, oak, maple and ash has also been reported (FRG, 1984).

The symptoms in conifers are a loss of needles, stunted growth, thinning of the tree tops, yellowing of needles and increased infection with insect pests and fungus (FRG, 1984). The yellow

needles exhibit magnesium deficiency (Binns and Redfern, 1983). In 1982 about 8% of the total forest area in the Federal Republic was said to be more or less badly affected. In 1983 a second survey put the affected area at 34% (FRG 1984 : Bell et al, 1984). The worst effects were in Bavaria and the Black Forest. Half the silver fir forest is reported moderately or severely damaged, although this species only makes up 2% of the total German forest area. Forty per cent of the spruce (which accounts also for 40% of forest area) showed some damage in 1983 (Bell et al 1984). The Germans assess current losses as costing about 1,000 million Deutschmarks per year.

Forest damage is also reported in the DDR, Czechoslovakia, Austria, Switzerland, Sweden and France. In the first two some at least is said to be due to acute pollution like we used to experience. There is no evidence of the continental type of damage in the UK (Binns, personal communication).

It seems clear that the forest damage is a genuine phenomenon, over a considerable area of Europe.

It is less clear what the causes are. The evidence is largely circumstantial and deductive (as is normal in ecology, where field experiments are difficult).

The German damage can certainly be correlated with altitude and exposure. Most of it is above 500 metres, and the worst is above 800 metres (Krause, 1984). The taller, older trees and those exposed at the edge of the forest are most affected. But it is creeping down the hills, and also beginning to affect more young trees (FRG, 1984). Other factors that correlate with damage are drought (the situation got suddenly worse after the dry summers of 1976 and 1983), and extreme cold. On the other hand the damage occurs on many different soil types. It does not fit with changes in cultivation practice. And the correlation with fungal and insect diseases is thought by most German foresters to be secondary (FRG, 1984).

The role of air pollution is at the heart of present concern.

It has been established in the laboratory that coniferous tree species are sensitive to a range of air pollutants, including sulphur dioxide, nitrogen oxides and ozone - and that several in combination can have a larger impact than one alone (Roberts, 1984). The effects of acid mists have also been studied. The difficulty lies in extrapolating these facts to the field situation.

Some of the German damage is in areas where sulphur dioxide concentrations are very high. In the Fichtelgebirge on the Czech frontier, half hourly peaks of up to 1700 micrograms of SO₂ per cubic metre have been reported and the effects there may very well be due to the direct impact of this gas, streaming across the frontier from the east. But in Southern Bavaria and the Black Forest, some affected trees are festooned by lichens, normally a good indication of low SO₂ levels. Moreover, sulphur dioxide concentrations in the air have been falling over recent years in much of Germany, as in the UK, while damage has been increasing. The direct effects of local industrial sulphur dioxide are therefore ruled out by many as the main cause of the German problem (Krause, 1984).

Superficially, the pattern of damage does broadly coincide with the area of highest rainfall acidity (Wallen, 1980). And while SO₂ levels have fallen, sulphate concentrations and rain pH have been more constant and nitrate has risen (Krause, 1984). But laboratory experiments using fumigation of tree seedlings with acid mists have failed to re-create symptoms like those seen in the field, and damage has normally appeared only at acidities considerably greater than those seen in natural rain (Jacobson, 1984).

It is now widely believed that a combination of air pollutants is involved.

A recent official German Government paper for the forthcoming conference in Munich presents such a view, saying :

'Initially, acid precipitation (acid rain) was seen as the main cause of damage : recently, however, opinion has tended towards

the idea that photochemical oxidants developed from nitrogen oxides under the impact of sunlight, and particularly ozone, also play a significant part'.

DOE has commissioned a review of the possible impact of ozone from the team at Imperial College led by Professor Jack Rutter, who are probably our best specialists. They state that 'ozone concentrations recorded at a Black Forest site (and three other rural mountain sites in Germany) are above those which have been shown in fumigation experiments to cause visible injury and growth reductions in certain sensitive tree species.' They think it 'quite plausible' that ozone is a factor in the German forest decline.

There are some experimental as well as field observations that suggest that ozone may be a primary agent of leaf cell damage, opening the way for percolating rainwater to remove calcium, magnesium and other vital nutrients. When spruce seedlings are exposed to a combination of acid mist and ozone, leaching of magnesium may rise by 20 to 30% - enough to account for the deficiency seen in the field. Calcium and sulphate were also present at enhanced levels in the water dripping from the branches.

The best present hypothesis is therefore that ozone (and probably also sulphur dioxide, where present in high enough concentrations) damages the leaf tissues, and that this increases the rate at which percolating rainwater removes essential ions. The more acid the rain, the higher the leaching rate. In turn, the roots are stressed in attempting to make good the deficiency. Cold and drought may aggravate the situation. In soils with little neutralizing capacity there may be an accumulation of acidity, leading to toxic aluminium ion release and a vicious cycle of deterioration. The details of the model are far from firm, but the point is that the present evidence points to acid deposition and ozone acting together.

This in turn affects our judgement of how the forests might respond to curative measures.

For it implies that sulphur dioxide concentrations may not be the most sensitive variable, and that reducing SO₂ emissions alone might well have only limited effect. It implies that total deposited acidity and ozone concentration may both be key factors, and this points to

action to curb nitrogen oxides and hydrocarbons as ozone precursors as well as SO₂. Some models imply that hydrocarbon concentrations are the primary determinant of ozone levels and that reducing nitrogen oxides would not ease the situation unless they were cut to very low levels (Eggleton, 1984). Other models involve action via the soil as well as directly on the foliage, and if these apply there could well be a time lag between reducing emissions and forest recovery : Ulrich (personal communication) has said that this could be measured in decades.

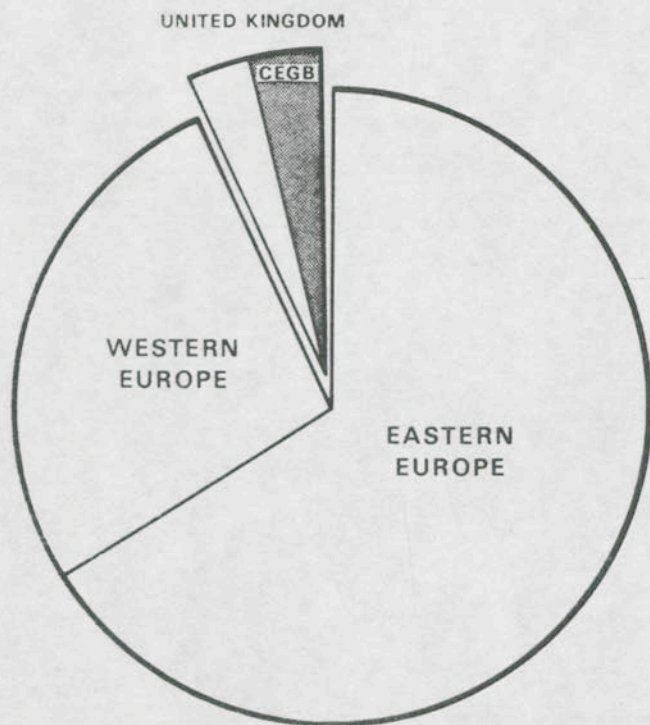
My personal view is that the recent hypotheses involving both acid deposition and ozone, with most impact where trees are stressed by climate, altitude or exposure, and with fungal pathogens and insects aggravating the situation once trees are weakened, is the most plausible. I therefore believe that remedial action may need to cover sulphur dioxide, nitrogen oxides and hydrocarbons. The German Government clearly takes this view, which is why they are seeking curbs on vehicle emissions as well as on those from power stations. And while forest damage is not now evident in the UK, it remains possible as does the confirmation of damage to sensitive crops and the evidence of acid corrosion of historic monuments. Reduction in these emissions would therefore be likely to bring some benefit to the UK environment.

Martin Holdgate
25 May 1984

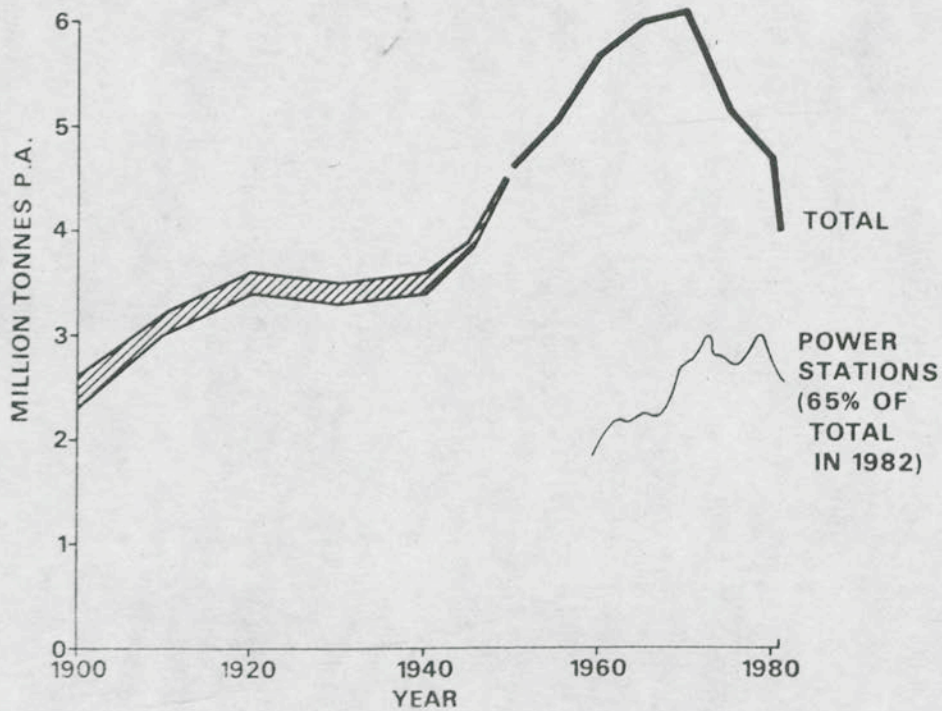
ABATEMENT

1. European SO₂ Emissions
2. Trends in SO₂ Emissions, UK
3. Trends in NO_x Emissions, UK
4. SO₂ Emissions and Sulphate Deposition
5. Precursors of Acid Rain
6. Hydrocarbons are Important
7. Points of Attack
8. SO₂: Coal Preparation
9. SO₂: Limestone Injection
10. SO₂: Flue Gas Desulphurisation
- 11 a/b FGD -- Size and Costs
12. SO₂: Fuel Switching
13. SO₂: Fluidised Bed Combustion
- 14 a/b NO_x: Combustion Control
15. NO_x: Flue Gas Treatment
16. CEEB Action Programme
17. SO₂: Contributions to Abatement

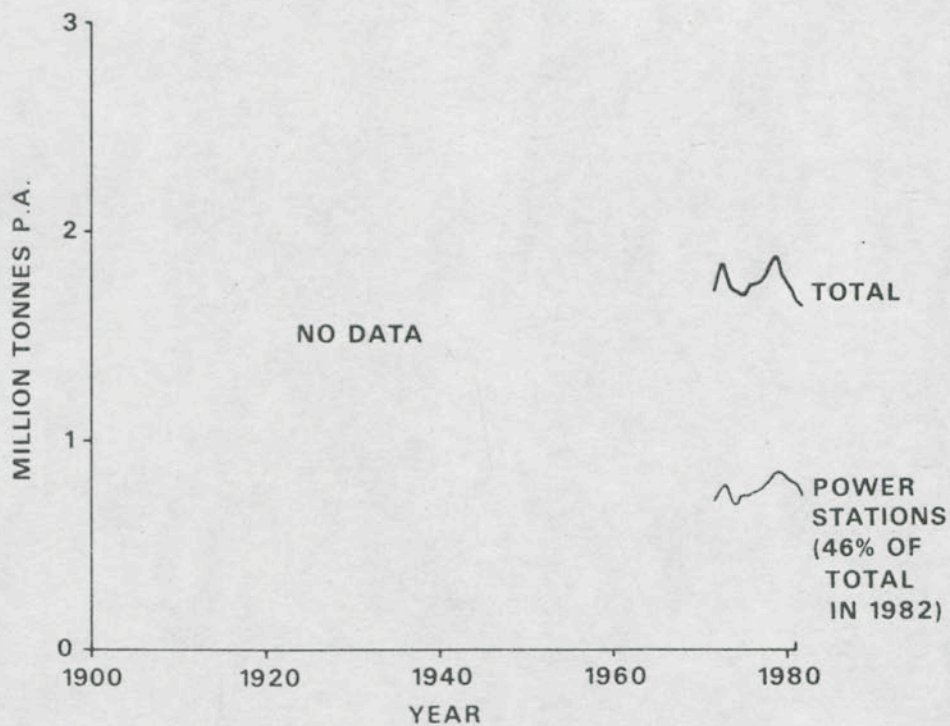
SULPHUR DIOXIDE EMISSIONS 1982



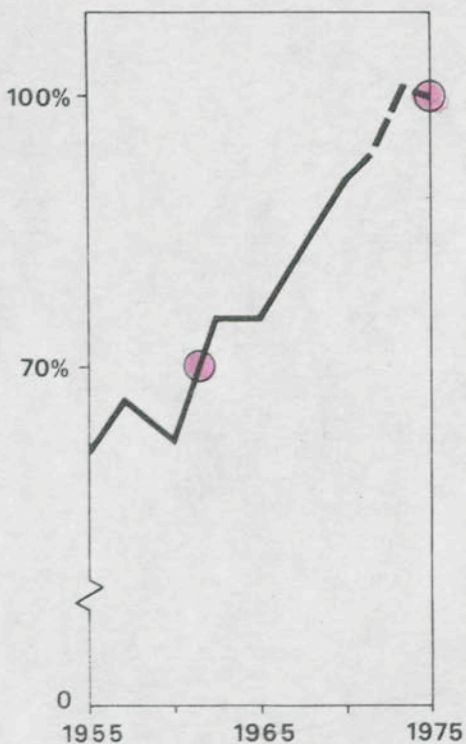
UK SULPHUR DIOXIDE EMISSIONS



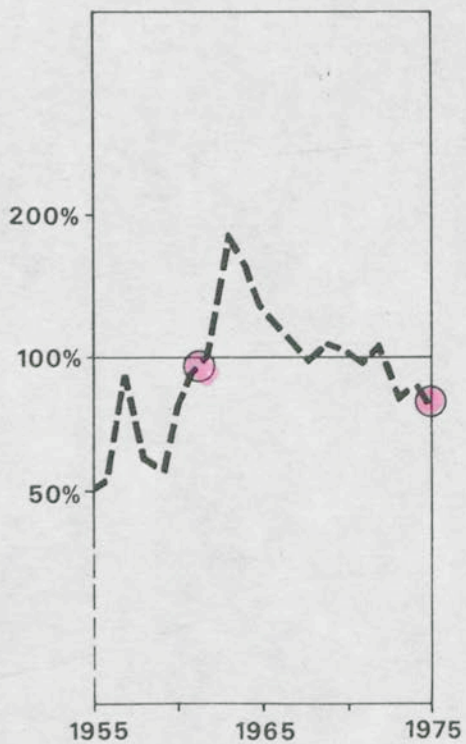
UK NO_x EMISSIONS

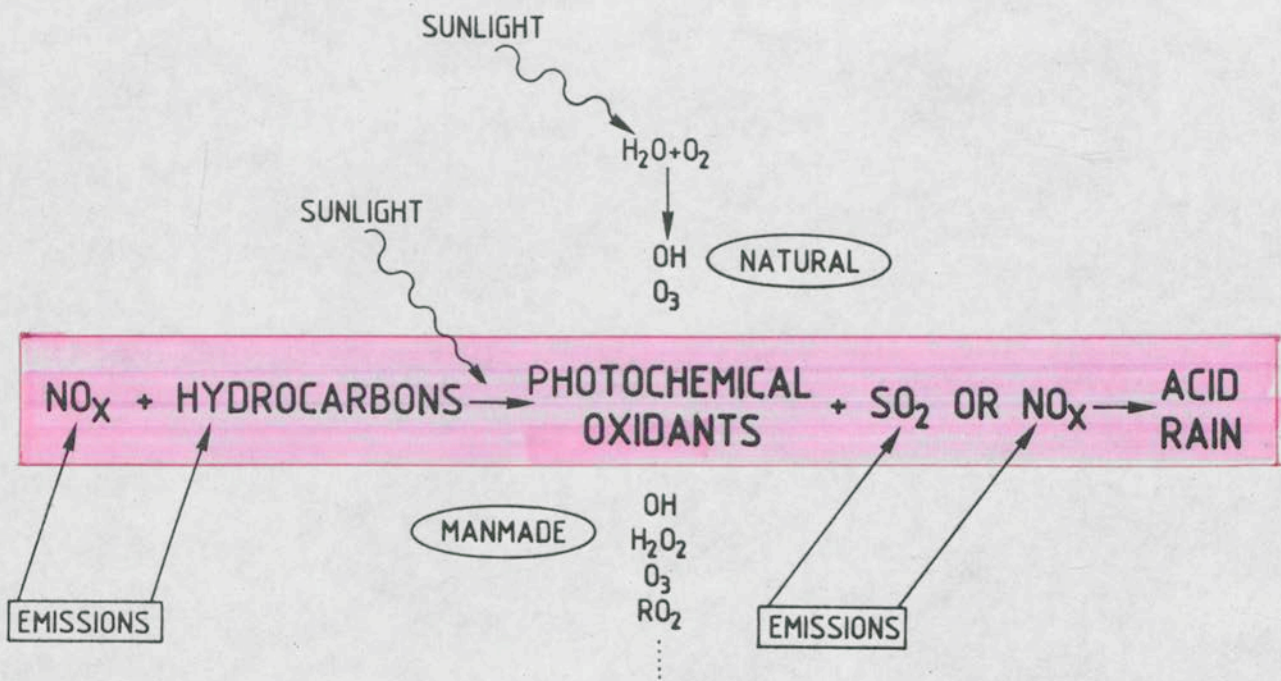


EUROPEAN SO₂ EMISSIONS

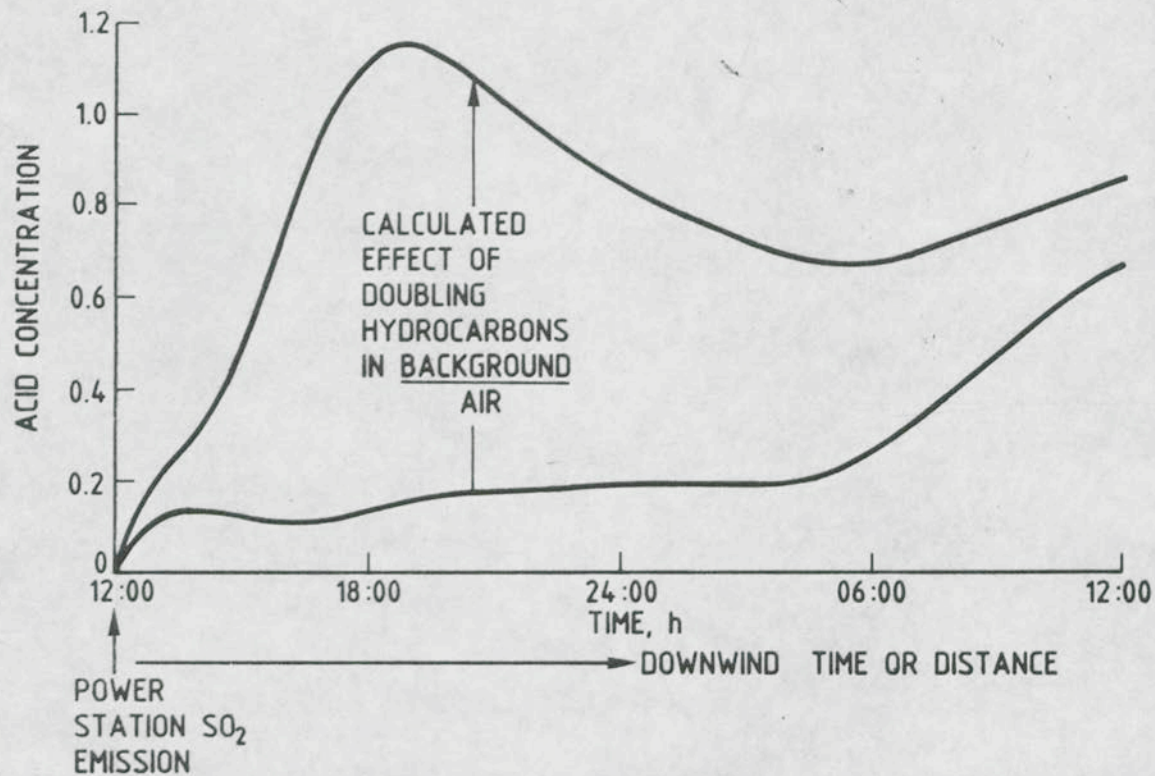


SCANDINAVIAN SULPHATE DEPOSITION



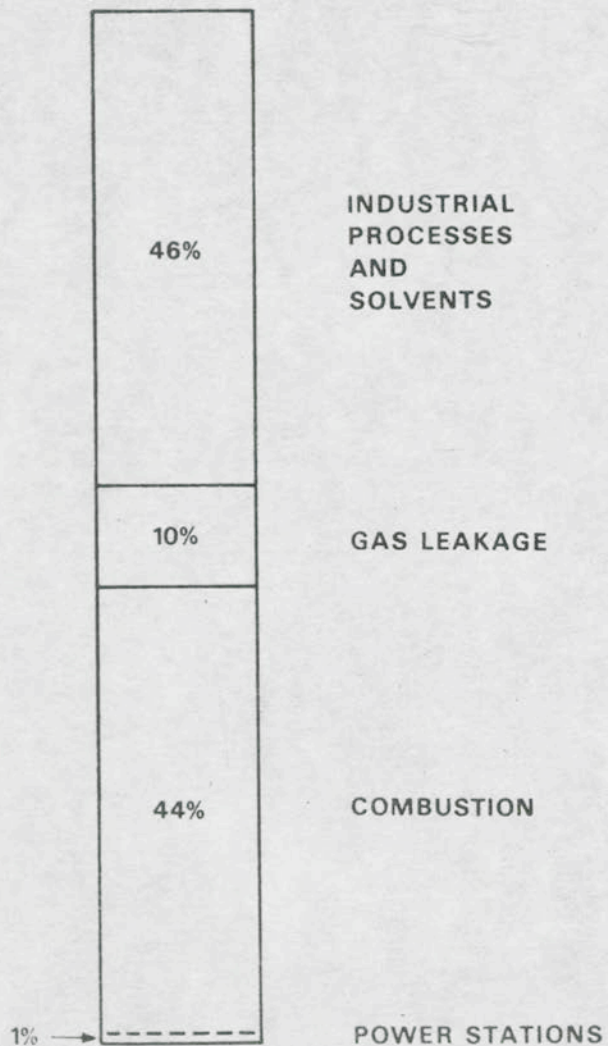


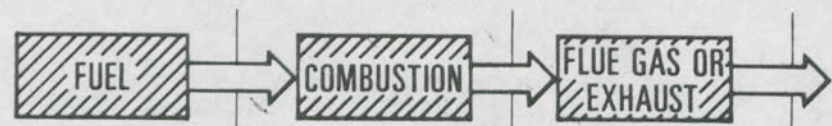
PRECURSORS OF ACID RAIN.



HYDROCARBONS ARE IMPORTANT

NON-METHANE HYDRO CARBONS 1982

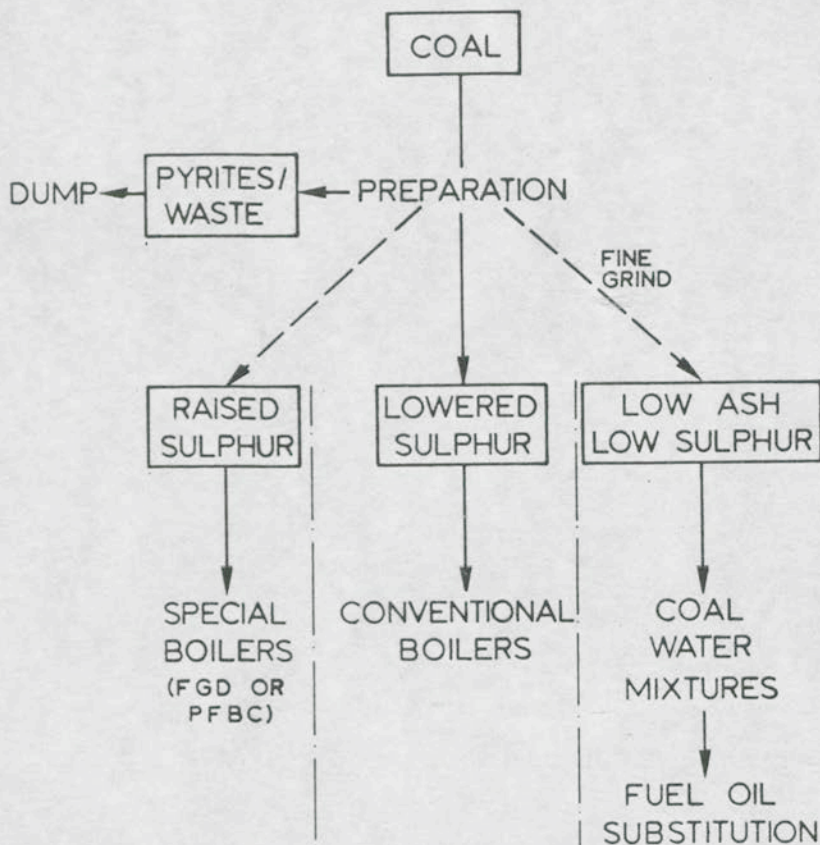




INDUSTRY & HEATING POWER STATIONS		SULPHUR (DIOXIDE)	SELECTION OR PROCESSING	ABSORB	WASH OUT	
		TRANSPORT		NITROGEN OXIDES	REDUCE FORMATION	CONVERT
				HYDRO-CARBONS	PREVENT LEAKAGE. ETC	EFFICIENT COMBUSTION

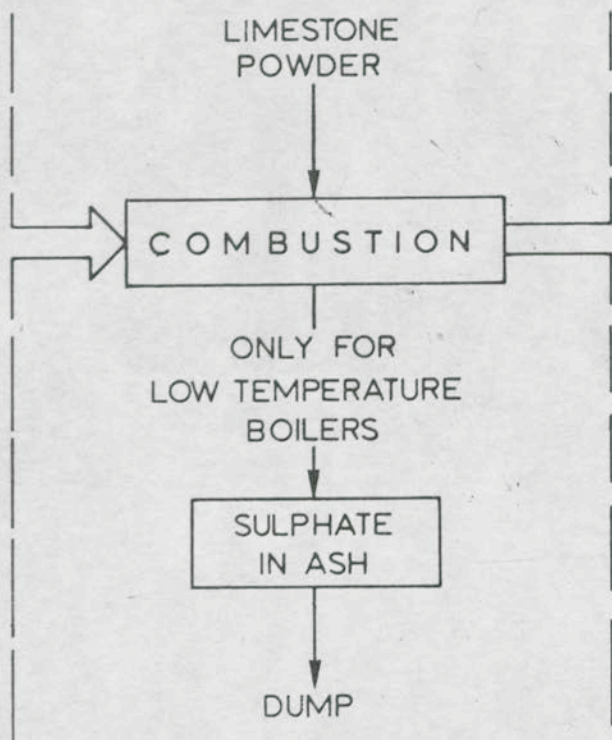
POINTS OF ATTACK

SO₂: COAL PREPARATION



SULPHUR EXTRACTED	—	~ 8%	UP TO 30%
COST/tonne SO ₂	?	£150 - £800	£1500 - £2500 (COAL) NO NET COST? (OIL)
STATUS	PAPER STUDIES	COMMERCIAL	DEVELOPMENT

SO₂ : LIMESTONE INJECTION



SULPHUR
EXTRACTED

UP TO 35%

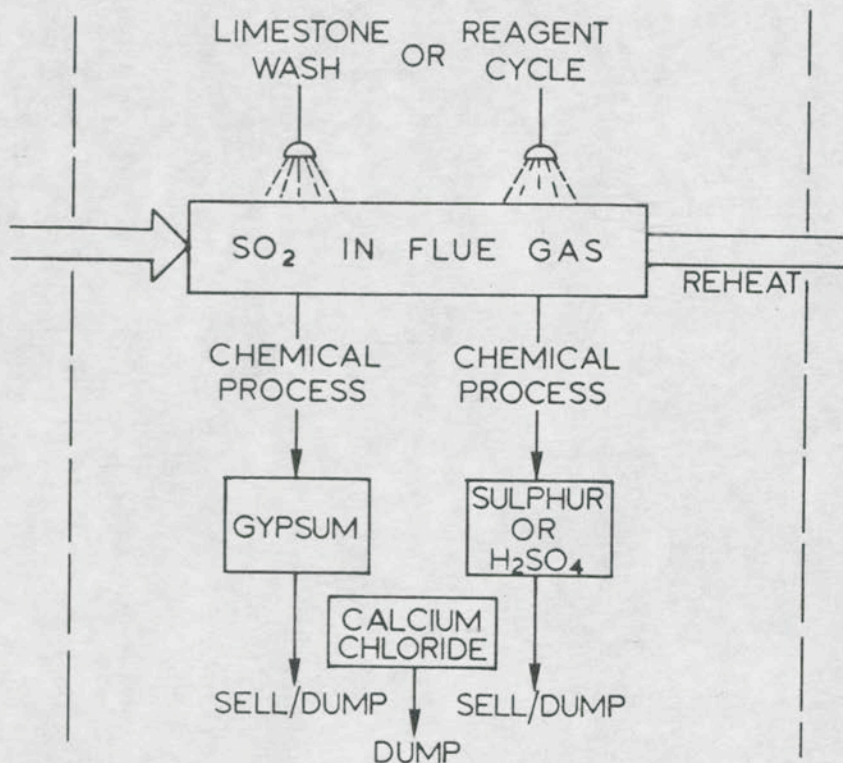
COST/tonne
SO₂

£400 PLUS

STATUS

UNPROVEN

SO₂ : FLUE GAS DESULPHURISATION



SULPHUR
EXTRACTED

90%

COST/tonne
SO₂

£200 - £400 (2000 MW(e))
£900 - £1600 (50 MW(t))

STATUS

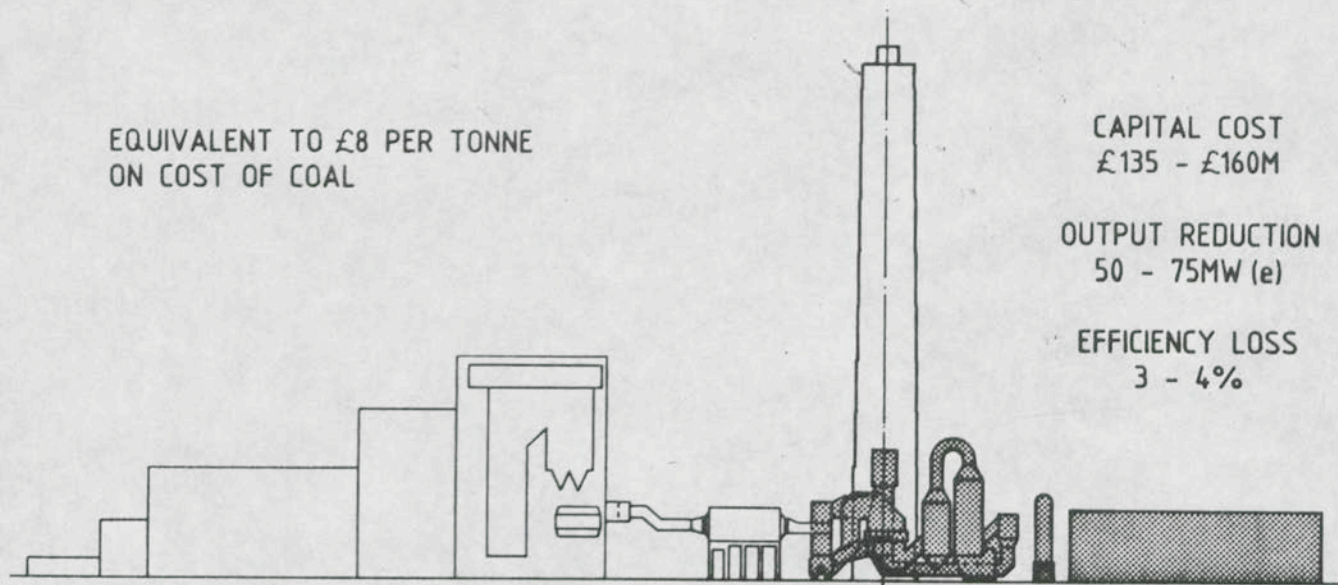
COMMERCIAL

EQUIVALENT TO £8 PER TONNE
ON COST OF COAL

CAPITAL COST
£135 - £160M

OUTPUT REDUCTION
50 - 75MW (e)

EFFICIENCY LOSS
3 - 4%



POWER STATION 2000 MW (e)

F.G.D. PLANT

COM(83)704

SO ₂ RETROFIT INVESTMENT		
REDUCTION ON 1980 %	TARGET DATE	
	1995	2000
60	£ 1400M	£ 1200M
30	£ 600M	£ 300M

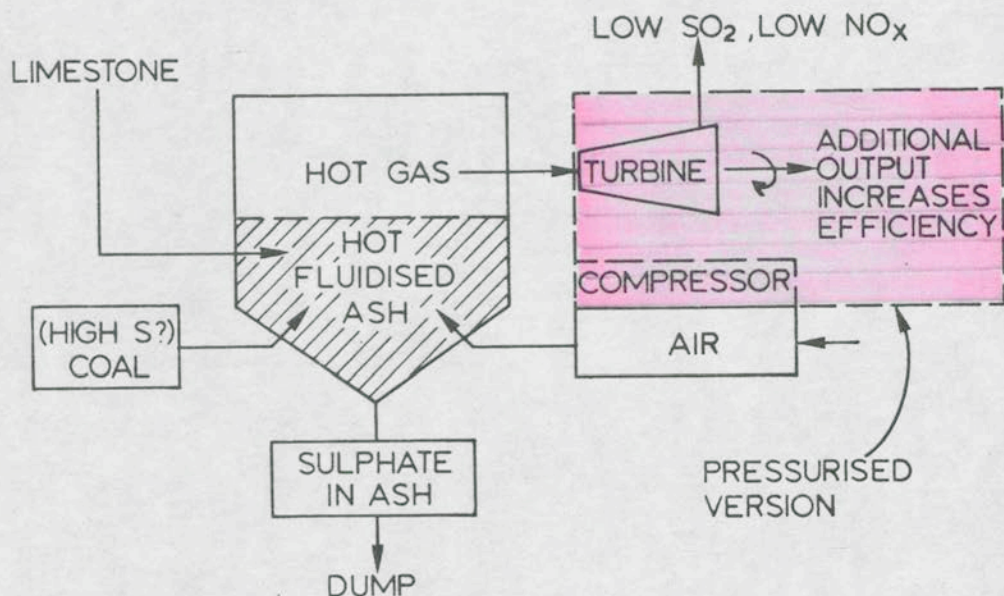
SO ₂ RETROFIT ANNUAL COST AT TARGET DATE		
REDUCTION ON 1980 %	TARGET DATE	
	1995	2000
60	£ 350M	£ 280M
30	£ 140M	£ 60M

(SCENARIO C, MEDIUM NUCLEAR)

SO₂ : FUEL SWITCHING

	LOW SULPHUR COAL IMPORTS	LOW SULPHUR OIL IMPORTS	"DESULPHURISED" OIL	NUCLEAR SUBSTITUTION
SULPHUR ABATED	UP TO 50%	UP TO 65%	UP TO 65%	98%
COST/tonne SO ₂	(SAVING £200?)	£200 - £300	£600 - £1300	(SAVING ~ £800)
STATUS	COMMERCIAL	COMMERCIAL	COMMERCIAL	COMMERCIAL

FLUID BED COMBUSTION



SULPHUR
EXTRACTED

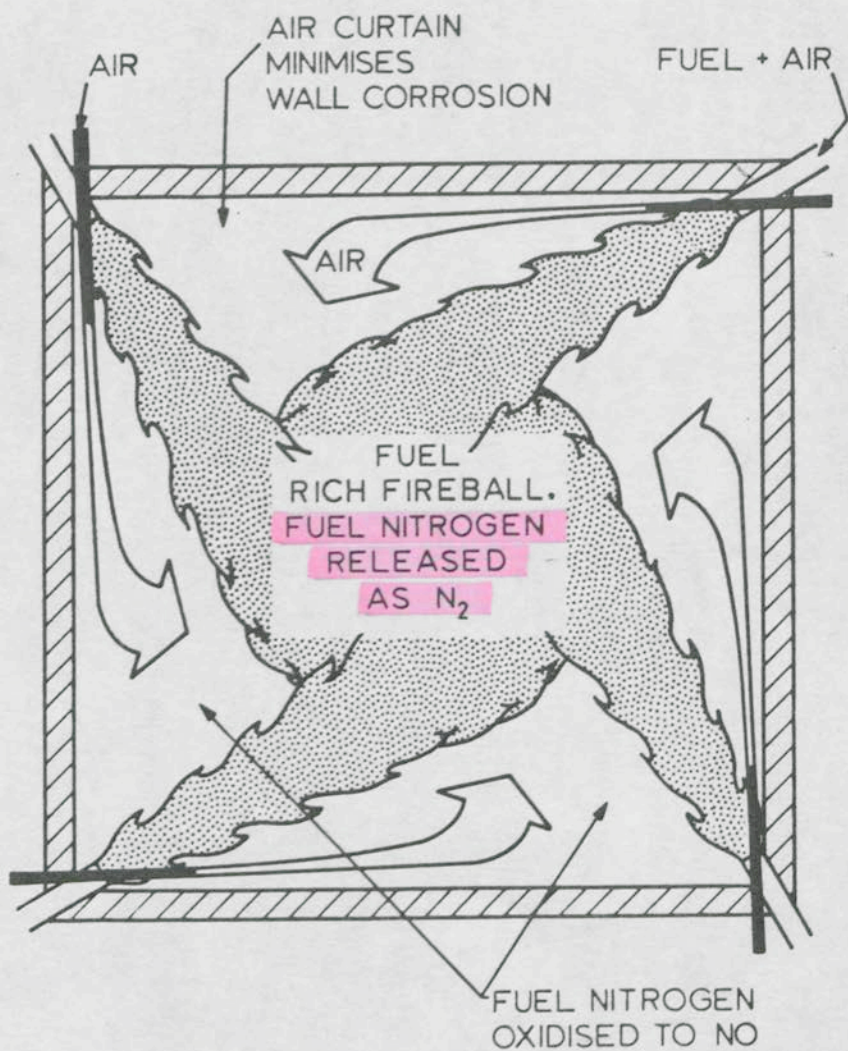
~60% ATMOSPHERIC
~80% PRESSURISED

COST/tonne
SO₂

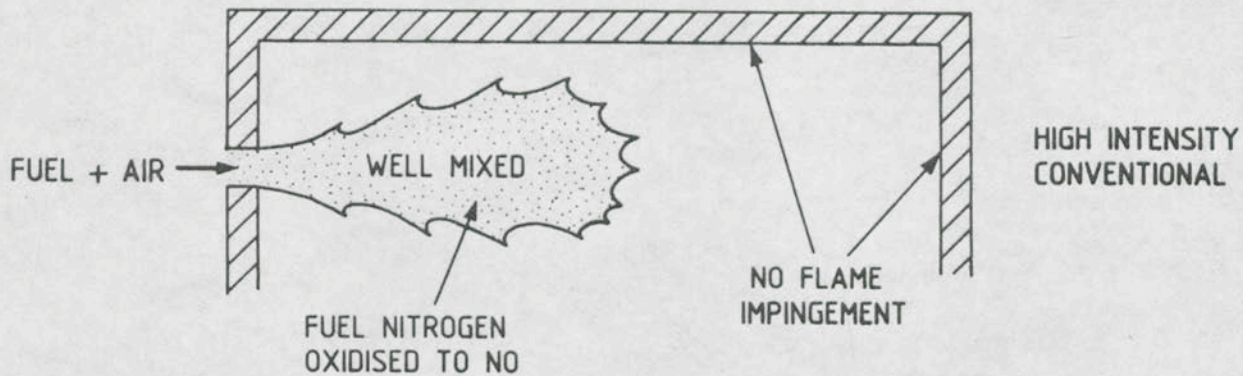
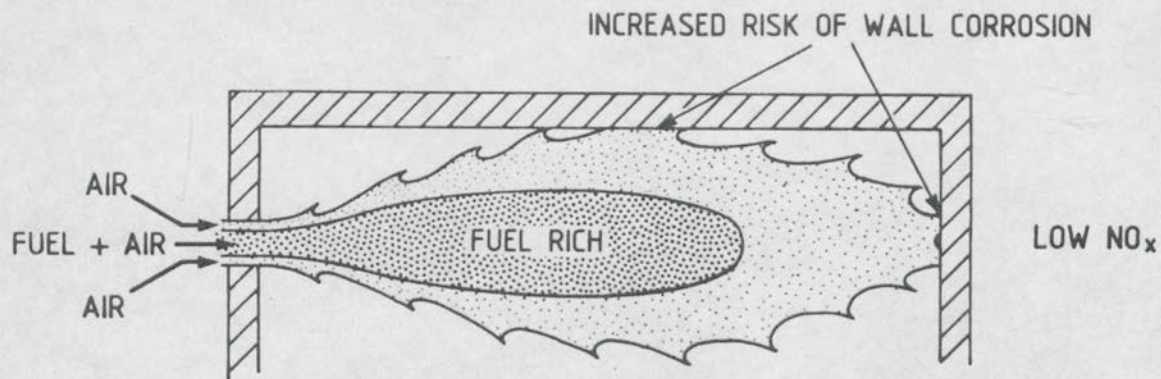
LESS THAN F.G.D.

STATUS

ATMOSPHERIC - COMMERCIAL DEMONSTRATION
PRESSURISED - FURTHER DEVELOPMENT AT
GRIMETHORPE (£25M+)



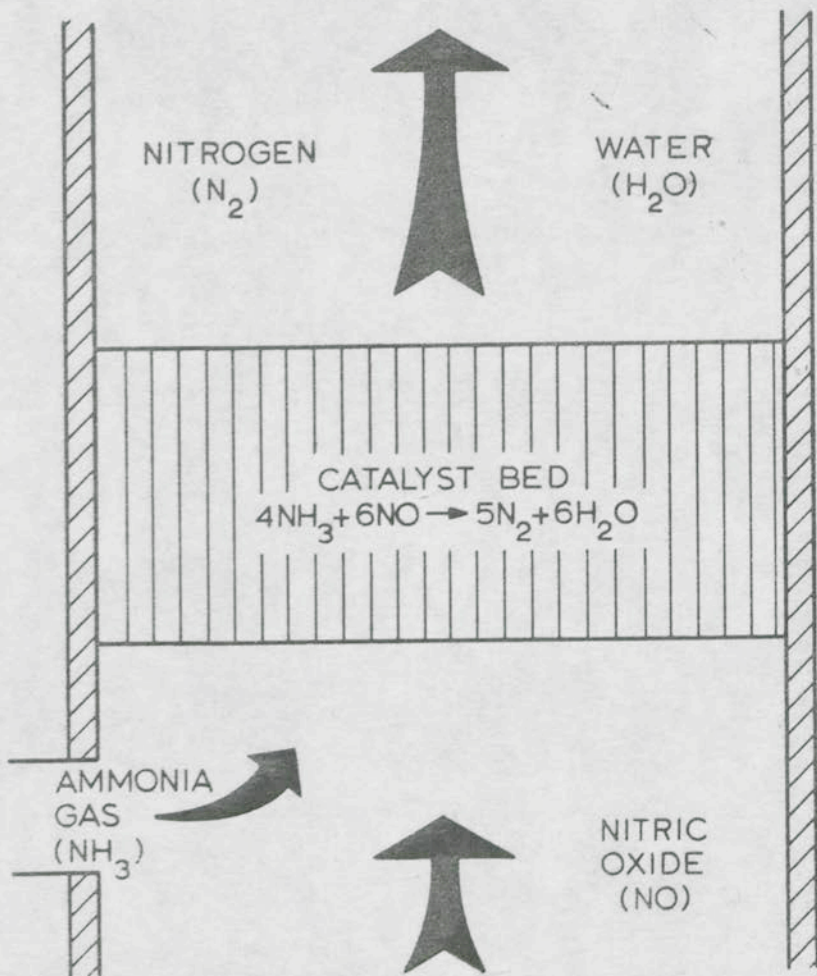
FUEL-RICH FIREBALL
PLAN VIEW



LOW NO_x BURNER (PLAN VIEW)

Cost approximately
equal to FGD
for NEW plant

~80% reduction



DRY FLUE GAS DE- NO_x

CONTROL TECHNOLOGY

CEGB ACTION PROGRAMME

SULPHUR DIOXIDE

POSSIBLE IMPACT

- | | |
|---|-----------|
| 1. Prepare for FGD if Necessary | Late 80's |
| 2. Explore Coal Preparation
- with NCB | Late 80's |
| 3. Develop Coal Water Mixtures | 1990 |

NITROGEN OXIDES

- | | |
|---------------------------------------|-----------|
| 4. Develop Low-NO _x Burner | Late 80's |
| 5. Pilot Rich-Fireball Trial | Late 80's |

SO₂ + NO_x

- | | |
|---|-------|
| 6. Develop Pressurised Fluid Bed
- with NCB (DEn) at Grimethorpe | 2000 |
| 7. Assess Gasification of Coal
- with BGC, NCB, DEn | 2000+ |

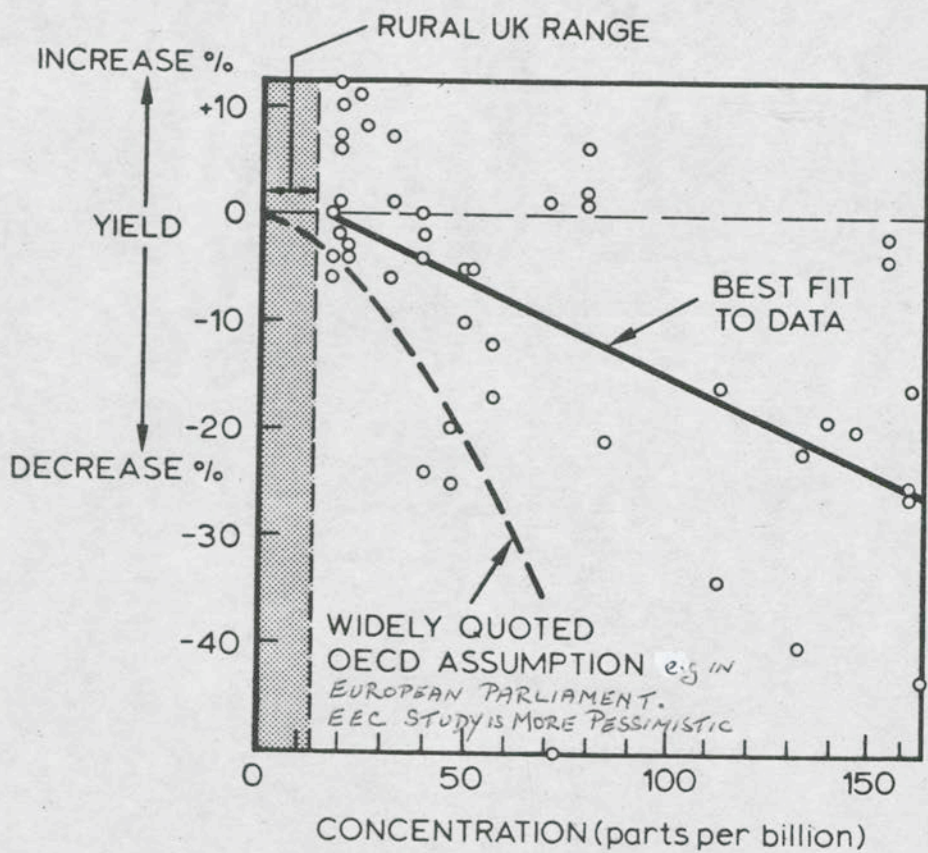
Cost ~ £ 50M Over 3 yrs

POSSIBLE CONTRIBUTIONS TO UK SO₂ ABATEMENT

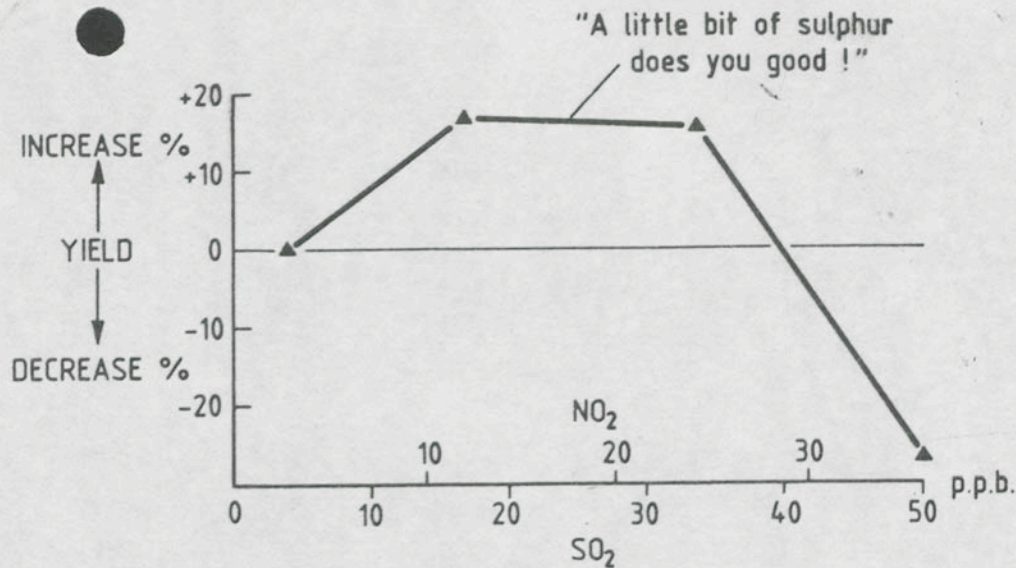
(UK 1980 ~ 4700 k tonnes SO₂, CEGB 55%)

	1995		2000	
	k tonnes	% of 1980	k tonnes	% of 1980
1. UK Reduction to 1982	(630)	(13)	?	
2. Two New 1100 MW Nuclear Stns.	160	3½		
3. Six New 1100 MW Nuclear Stns.	-	-	450	10
4. FGD, Retrofit to Power Stations	1500	32	1800?	38?
5. Controls, Other Industry	400?	9?	500?	11?
6. Coal Preparation	100	2	?	
7. 5 Mt Low S. Coal Import	100	2		
8. Refineries	?		?	
9. 10 Mt Low S. Fuel Oil	150	3		
10. 10 Mt Oil Substitution by Coal Water Mixture	70	1½	?	

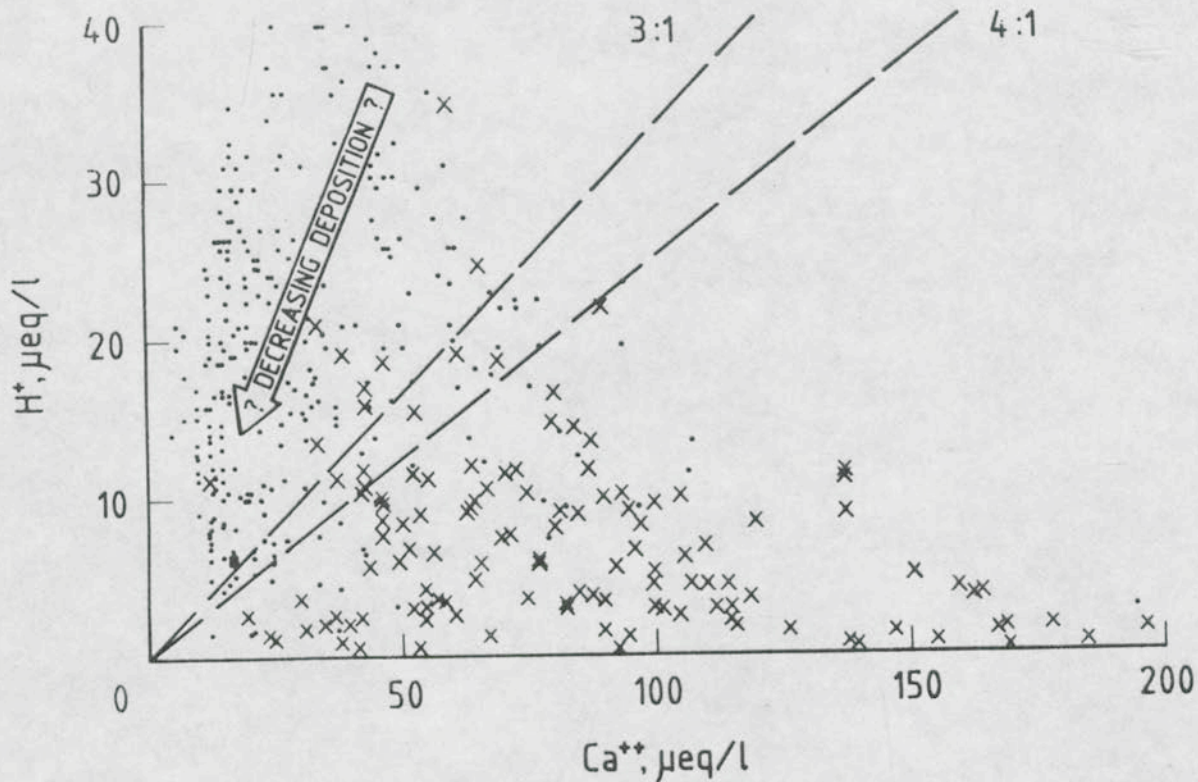
NOT ALL ADDITIVE



EFFECT OF SO₂ ON RYEGRASS
(1981)

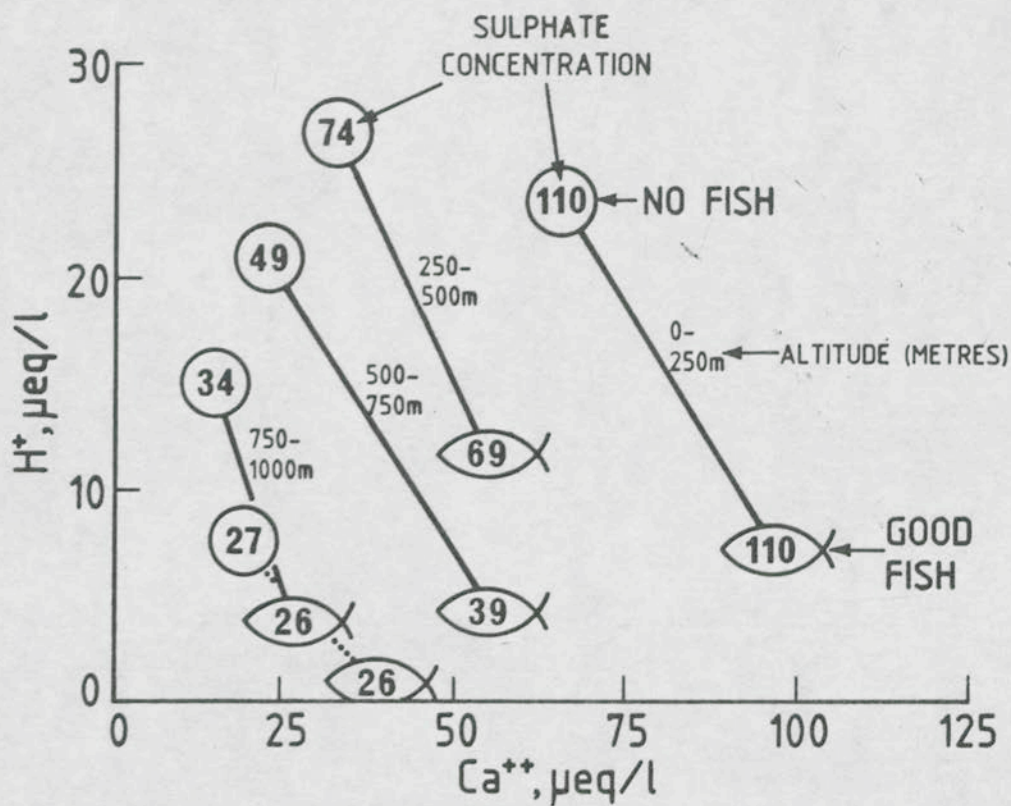


EFFECT OF SO₂ & NO₂ ON WINTER BARLEY (1984)



• NO FISH x GOOD FISH

NORWEGIAN LAKES



NORWEGIAN LAKES - FISH STATUS
AND SULPHATE LEVELS

OBJECTIVES ACCEPTED BY THE ROYAL SOCIETY
AND THE SCANDINAVIAN ACADEMIES

1. In the affected areas of Southern Scandinavia, what are the factors, in addition to pH, that in practice determine the fishery status of lakes?
2. What are the biological, chemical and hydrogeological characteristics of catchments which determine whether the composition of surface waters falls within a range acceptable to fish?
3. In Southern Scandinavia, to what extent are these characteristics being adversely affected by the acid deposition itself?
4. What changes would be brought about in water chemistry and fishery status in Southern Scandinavia by given levels of reduction of man-made sulphur deposition?

These are ALL concerned with soil, water and fish.
NOT with forest damage.

IF the Academies believe there is good scientific reason to extend their work to forests, the CEGB has agreed to fund the extension.

SWEDISH CONCERN ON FORESTS

1972, Stockholm Conference

"We have found no good reason for attributing the reduction in growth to any cause other than acidification"

1982, Stockholm Conference

"The analysis . . . has not confirmed the declining growth that had earlier been implied. Norwegian investigations . . . have likewise been unable to establish any diminution of growth in the areas considered sensitive to acid precipitation"

1983, South Sweden

"Dieback" observed after one of the driest, sunniest summers on record for a century.