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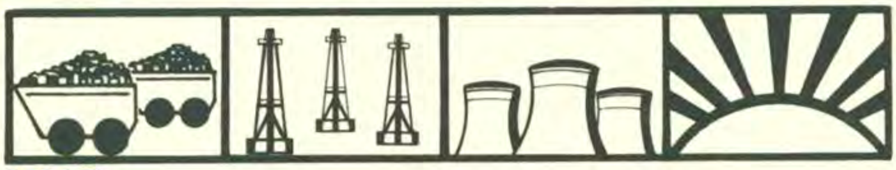

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The Environmental Impacts Of Production And Use Of Energy

Part I. Fossil Fuels

REPORT OF THE EXECUTIVE DIRECTOR

Nairobi, September 1979

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PREFACE

Energy has long been viewed as an essential ingredient in meeting basic human needs and in stimulating and supporting economic growth and a rising standard of living. Historically, energy has been thought to be cheap and plentiful. Recently, however, it has been realized that fossil fuels, especially oil, are finite in extent and should be regarded as depleting assets, and the term "energy crisis" has become a common catchword all over the world. However, it is difficult to define this "crisis". Does the problem lie in the scarcity, or the vulnerability, of supply? Or is it the rising cost of energy resources as an important cause of the world-wide inflation and recession? Or is the crisis defined by an "excessive" demand for energy, or by widespread habits of energy waste? Of course, it may be all of these things.

At local, national and in some cases regional levels, the environmental aspects of energy production and use have become the subject of wide-ranging debate. Environmental awareness and anti-pollution campaigns have affected the formulation of energy policies in many countries, and it has recently been realized that nations are not isolated in this respect; the actions of one country may affect the environment in a neighbouring one. Environmental objectives should not, however, be seen as being inconsistent with, or as imposing constraints upon, energy policy. A balance should be maintained betwen the need to preserve and improve the quality of the environment and the socio-economic goals and needs which depend on the availability of energy. Nowadays, energy policy decisions are dictated less by technological than by social, environmental and political factors. Although some countries are sensitive to the environmental aspects of energy production and use, there is still need for a comprehensive and more coherent consideration of the subject.

One of the tasks assigned to the Governing Council of the United Nations Environment Programme by the General Assembly of the United Nations in its resolution 2997 (XXVII) of 15 December 1972 is to:

> "keep under review the world environmental situation in order to ensure that emerging environmental problems of wide international significance receive appropriate and adequate consideration."

In this respect, the Governing Council of UNEP considered at its fourth session (March/April 1976) a review of the environmental impact of production and use of various forms of energy. As a follow-up to this report, the Governing Council requested the Executive Director to undertake more detailed studies of the environmental impacts of the production, storage, transport, and use of energy.

The present report was prepared by Dr. Essam El-Hinnawi of the UNEP secretariat on the basis of contributions written by a number of scientists and information compiled by UNEP. It was reviewed by an international panel of experts that met in Warsaw in April, 1978 and revised and finalized according to the comments of the members of the panel.[1] It deals with the environmental impacts of the production, transportation and use of fossil fuels and is the first in a series of studies on the environmental impacts of different sources of energy. The second report in the series, dealing with the environmental impacts of nuclear energy, is being published, while the third report, on renewable sources of energy, is in preparation. A fourth report concluding this series of studies will aim at a comparative assessment of the environmental impacts of these various sources of energy, and will be published in 1980.

The production, transportation and use of fossil fuels, especially coal, raise a number of important environmental issues. Among these, questions of the availability and allocation of resources are likely to play an important role as pollution problems proper. Land and water use, emissions (including thermal discharges) and their impact on ecosystems and human health are but examples of the problems to be encountered.

Concern has been recently voiced at the implications of extensive coal utilization, especially its possible impact on climate. The atmosphere is believed to show a warming primarily due to the greenhouse effect of increasing carbon dioxide emissions. The important question is: what will the regional changes of temperature and rainfall be? Studies with climate models and of climate observations indicate that regional anomalies will probably occur, but the magnitude and impact of these anomalies cannot be reliably predicted at present. The medium and long-term effects of such possible climatic changes are of such fundamental importance that they command serious attention.

It is my sincere hope that this report will be found to give a balanced assessment of the environmental impacts of fossil fuels as seen by the international experts in the field and as viewed by the United Nations Organ responsible for the safety of the Environment at the global level.

I would like to express my gratitude to the scientists who prepared background papers for this study and to those who participated and helped in the review process.

Mostafa K. Tolba
Executive Director

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[1] For a list of experts, see Annex I.

CHAPTER I

INTRODUCTION

1. Energy is one of the most important pre-requisites of life. Without energy our entire civilization - transport, industrial manufacturing, commercial activity and food production - would come to a standstill. Since prehistoric times human society has been consuming a constantly increasing amount of energy. The modern industrial era brought with it a marked increase in consumption of energy and changes in energy sources from wood and coal to predominantly oil and natural gas. The relationship of economic prosperity to energy consumption has become an essential element of energy policy, for it couples the latter to economic policy and the general national welfare. Although there are anomalies in the amounts of energy required in different countries to achieve a given level of gross national product (GNP), there is nevertheless a rather consistent relationship between GNP and energy consumption.

2. The rising global demand for energy has been met to an increasing extent by the use of fossil fuels, especially oil, which were cheap and plentiful. Recently, many countries have realized that non-renewable sources of energy are finite in extent and that diversification of energy sources is a must for future development. Concern for future energy supplies is reflected in the programmes of many national governments and in the efforts being made by a number of international organizations to assess global energy resources and possible rates of supply and substitution. Energy policies are nowadays influenced by several factors: population growth, level and nature of socio-economic activity, the relative costs of energy, the adequacy and reliability of supply, the availability of technology and supporting infrastructure, the success of energy conservation programmes and concern about the environmental and safety aspects of production and use of energy.

3. World energy consumption increased almost 600 per cent between 1900 and 1965 and is projected to increase another 450 per cent between 1965 and the year 2000. Most of the world's consumption of energy from fossil fuels throughout all history has taken place during the past 40 years. Estimates of future demand and supply vary considerably, depending on the assumptions made about resource availabilities, economic growth, pricing policies, the responsiveness of energy demand and supply to changes in prices and incomes, and political and environmental factors. Recently, it has been illustrated that, after 1985, world demand for energy is likely to outstrip supply (World Bank, 1979). Supply of oil is predicted to fail to meet increasing demand before the year 2000 (WAES, 1977).

4. Industrialized countries dominate the energy market, accounting for more than a third of world production and more than half of world consumption. Together with the centrally planned economies, they account for about 66 per cent of world energy production and about 85 per cent of world consumption. The developing countries with more than 52% of the world population account for about 14% of world energy consumption (World Bank, 1979).

5. Energy production in industrialized nations is expected to increase by about 3 per cent a year between 1976 and 1990. Coal and nuclear power are expected to account for a substantial part of the anticipated production increases, with relatively modest overall increases in petroleum and natural gas production. Some of the major issues affecting the development of coal and nuclear power are environmental preservation, safety, and the uncertainties related to oil prices. These factors have resulted in long delays and cost overruns in nuclear power development - problem that are likely to be exacerbated by recent events in the US nuclear power industry, which have heightened the sensitivity to safety hazards and increased the costs of insuring against them (World Bank, 1979). Increased reliance on coal-fired electricity, including the conversion of existing oil-fired plants, poses several economic and environmental problems.

6. The growth of energy consumption in developing countries slowed down to an average of about 5 per cent a year during 1973-76, though it was typically faster than this in oil exporting developing countries. Electricity consumption continued to increase rapidly, with its share in total energy consumption rising from 16 per cent in 1960 to 25 per cent in 1976. In the years 1976 to 1990, the developing countries energy consumption is expected to grow faster than in industrialized countries, reflecting their higher expected economic growth rates and rising levels of industrialization and urbanization. Moreover, commercial energy is likely to substitute increasingly for non-commercial energy in developing countries. Their share in world energy consumption is expected to rise from about 14 per cent in 1976 to about 17 per cent in 1990 (World Bank, 1979).

7. The energy problem over the next two decades should be seen as one of transition, in which countries need to adjust to higher energy prices, to ensure the rational, non-wasteful use of the non-renewable sources of energy and to diversify their sources of energy establishing an appropriate and environmentally realistic "energy mix" to meet their incremental needs.

Environmental Impacts:

8. The present report aims at reviewing the environmental impacts associated with the production, transportation, processing and use of fossil fuels. It is, therefore, important to define what constitutes an environmental impact for the purpose of this study.

9. Consideration of the Declaration and Principles of the United Nations Conference on the Human Environment convened in Stockholm in 1972 shows that the environment - defined as the whole outer physical and biological system in which man and other organisms live - is a whole, albeit a complicated one with many interacting components. The wise management of that environment depends upon an understanding of those components: of its rocks, minerals and waters, of its soils and their present potential vegetation, of its animal life and of its climate. Good management avoids pollution, erosion, and the wastage of resources by irreversible damage. To prevent such types of environmental degradation is even more challenging and certainly more efficient than to redress them after they had occurred.

10. Of the many potential environmental impacts associated with any particular energy technology, some would be substantial and others small, some important and others of little consequence, some of short duration and others with long term effects, some might be adverse and others beneficial and they might occur in different geographic areas and might affect different communities in different ways. A distinction should be made between the assessment of the nature, scale and geographic distribution of the impact, and the evaluation which is concerned with its value or importance. For many environmental changes which are identified as impacts, the state of knowledge and technology will often only permit a qualitative assessment. Only in a few cases is it possible to evaluate an impact quantitatively. Decisions must ultimately be made on the basis of combination of cost/benefit analysis, other quantified inputs and qualitative information.

11. Discussion of the environmental impacts of various energy strategies has, in the past, tended to focus more attention on short-term aspects, such as occupational and public health and direct impacts on the physical environment, than on the long-term socio-economic and environmental consequences. However, there is now a growing disposition to analyse these long-term impacts which may range from those for which substantial data exist and around which there is a fair degree of certainty as to the risks involved, to those which are rather speculative in nature and for which very little data are available.

12. The biosphere consists of different organisms, plants and animal life supported by a number of physical characteristics such as topography, soils, climate, water supply and drainage. For a given development, these physical characteristics and hence the biosphere may be affected. Whenever pollutants are released, the analysis of the environmental impact of these pollutants requires the knowledge of the:

(a) quantity and types of pollutants released;
(b) dispersion of these pollutants in the environment;
(c) ecological pathways followed by the pollutants;
(d) relationships between the pollutants and the damage to man and his environment;
(e) the extent of the damage including its cost (where it is possible to make this assessment).

13. The total impact of some pollutants may depend on positive or negative synergistic effects. Although standards have been formulated for "acceptable" levels of several pollutants, it is prudent to assume that for exposure to many pollutants there is no threshold and that effects can occur at very low exposures. A further feature is that many pollutants may remain in the environment (and accessible to the food chain) long after the action releasing them has been discontinued. Attempts to assess the long-term impacts of these pollutants, although difficult, should be made taking into consideration the different pathways, biogeochemical cycles and fate of these substances in the environment.

14. The assessment of environmental impacts resulting from the different stages of any fuel cycle is important in relation to policy-making and decisions about energy options or "mixes" to be developed. The conservation of the natural environment is essential to the maintenance and regulation of the food, air and water cycles on which human life depends and to socio-economic development. The most important impacts of any energy technology on the human environment are probably the impacts on health and safety and on social well-being.

15. An important part of the overall risk assessment process for the various energy options is the attempt to quantify the total harm to man and his "life-support-systems" caused by energy pollutants, e.g. radionuclides, potentially toxic heavy metals, polynuclear aromatic hydrocarbons (PAH), nitrogen oxides (NO_x), sulphur oxides (SO_x) ... etc. These act directly (via inhalation, ingestion) or indirectly (via biogeochemical cycles and the human food-chain) to affect human health, agricultural or resource productivity, or to cause nuisance or other dis-amenities (e.g. corrosion). Although the amount of this risk is now a days being worked out separately for each energy option on a comparative basis, traditionally, environmental health authorities have tried to assess the amount of harm to people resulting from direct or indirect exposure to various doses of a pollutant whatever its origins, i.e. in a more general way taking into account all its sources together.

16. Using experimental animals as substitutes for man, toxic effects (particularly acute effects) have frequently been found to follow a sigmoid curve with dose where, below a certain level of pollutant virtually no effect is found. This type of dose-effect relationship is often confirmed by occupational health statistics (i.e. at relatively high pollutant levels). As a consequence, attempts have usually been made to derive safety standards and "clean-up" procedures for pollutants in the various environmental media of air, water, soil, food ... etc., so that they ultimately deliver a dose to man below a "safe" level, thus avoiding harm altogether. However, apart from acute and sub-acute effects caused by relatively high pollutant doses, there are longer term effects on living organisms (including man) usually associated with smaller doses, e.g. chronic illness, carcinogenic, mutagenic or teratogenic effects. All these may appear much later on in the life-cycle or even be delayed until later

generations. Chronic, and particularly "late" effects are more and more coming to be regarded as being linearly (not sigmoidally) related to dose, very low doses or repeated incremental doses sometimes even appearing to exhibit higher than expected effectiveness on a linear basis. In fact several of those pollutants formerly known as producing sub-acute and chronic effects are also now being shown to cause genotoxic effects and hence exhibit a linear dose-effect picture over the lower part of their toxicity range.

17. Linearity of the dose-response relationship effectively means that when making an evaluation of risk, account must be taken of the probability that a harmful effect will be induced <u>at any dose, however small</u>. The existence of linearity in dose-response curves is further complicated in some instances by pollutant distribution dynamics in the environment, and by the fact that health risks are attributed to combined (synergistic) effects of more than one pollutant. Furthermore, a particular pollutant being emitted from an energy producing process may be altogether swamped by vast quantities of the same pollutant coming from non-energy processes and so it is prudent to keep a sense of this perspective when calculating energy related risks.

18. Fossil fuels (coal, oil and natural gas) are used for many purposes: domestic, industrial, transportation and for electricity production. In 1976, about 73.2 per cent of the electricity production in the World was from fossil fuel fired power plants (see Table 1). Therefore, the environmental impacts of the different stages of the coal-, oil- and natural gas- fuel cycles* in this report are quantified (when feasible) on the basis of 1000 MW(e)y (1 GW(e)y) for easy comparison.

Table 1. <u>World Electricity Production (in 10^9 kwh)</u>**

Year	Thermal	Hydro	Nuclear	Total
1972	4226	1294	144	5664
1973	4583	1313	191	6087
1974	4580	1439	246	6265
1975	4660	1459	343	6462
1976	5063	1456	398	6917

** After: World Energy Supplies 1972-1976, United Nations (1978).

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* The "fuel cycle" refers to the entire programme from the extraction of raw material, through transportation, processing, storage, use of the fuel, to the management of wastes produced in all steps of the cycle.

CHAPTER II

COAL

19. Coal has long been used as an energy source and it occupied a prominent position amongst fossil fuels at the beginning of the present century. The importance of coal declined after the extensive discoveries of oil, which has, until recently, been cheap fuel. Nowadays, special emphasis is being made on expanding the production and use of coal to reduce the dependence on the fast-depleting oil resources.

20. Table 2 gives the annual production of coal in the World in 1975-1977 showing only a slight increase in total production; the average per capita consumption of coal in 1976 was about 2600 kg. The total world resources of hard coal and brown coal have been estimated at 10,130 x 10^9 tonne coal equivalent (tce); the reserves that are currently technically and economically recoverable are estimated to be about 640 x 10^9 tce, i.e. 6.3% of known resources. It is expected that this amount will double by the year 2020 (Grenon, 1978).

Table 2. World Production of Coal (in million metric tons)*

	1975		1976		1977	
	H.C.	B.C.	H.C.	B.C.	H.C.	B.C.
Africa	75.4	0.1	81.2	0.1	85.5	0.1
N. America	595.0	21.5	603.5	27.9	631.4	32.8
S. America	7.9	0.1	9.4	0.1	9.8	0.1
Asia	652.6	20.1	673.4	23.2	698.3	26.1
Europe	475.9	630.3	482.0	655.0	486.0	700.0
Oceania	62.2	30.1	70.1	31.1	73.3	33.2
U.S.S.R.	484.7	160.2	494.4	192.8	500.0	206.0
World	2353.7	862.4	2413.7	930.8	2475.1	998.3
Total coal	3216.1		3344.5		3473.4	

* H.C. : Hard coal with thermal value greater than 22000 Btu/kg;
B.C. : Brown coal and lignite with thermal value less than 22000 Btu/kg.
After : World Energy Supplies 1972 - 1976, United Nations (1978)

21. Table 3 gives the estimates of coal resources and the technically and economically recoverable deposits.

Table 3. World Coal Resources (in 10^6 tce)*

	Geological Resources		Technical and Economically recoverable	
	H.C.	B.C.	H.C.	B.C.
N. America	1,286,225	1,399,525	121,938	65,031
S. America	25,106	9,263	4,901	5,860
Asia	5,494,025	887,127	219,226	29,591
Europe	535,664	53,741	95,010	33,752
Africa	172,714	190	34,033	90
Oceania	213,890	49,034	18,164	9,333
Total World	7,727,624	2,398,880	490,272	143,657

* After Grenon (1978).

22. The expansion in coal production is faced by a number of obstacles, the most important of which are: the availability of qualified miners and engineers; the construction of a suitable infrastructure and of adequate transportation facilities; various environmental problems, which need to be solved, both in production and in consumption; the fact, that at present potential markets for coal are not yet sufficiently being developed in many parts of the world, since other sources of energy are still being offered at competitive prices; the lack of interest on the part of potential investors to commit themselves to the development of coal; the long lead times required for opening up new mines, establishing the necessary infrastructure, transportation facilities,etc.

Environmental Impacts of Coal Mining

23. Coal can be mined, according to its geological setting by a variety of methods, the most common of which are underground mining (room and pillar or long-wall techniques) and strip mining (area or contour). Recovery factors of 100 per cent are not possible in practice; at present the average recovery factors in most coal producing countries are around 35 per cent in underground room and pillar mining, 60-80 per cent in underground mining of long-wall faces and 80-90 per cent in surface mining (ECE, 1976). The amount of coal to be mined depends on the energy content of the coal, which varies with its type and its use - whether for domestic purposes, industry (steel, cement...etc.), electricity generation, or a combination of these.

Occupational Hazards:

24. Coal mining has a number of occupational hazards. Besides accidents in underground mines (fires, explosions, land subsidence, etc.) and in surface mining, coal-workers are exposed to respiratory diseases and noise.

25. Based on statistics for the period 1971 to 1975 in the U.S.A., the accident fatality rate in underground coal mining has been estimated to be 0.4 deaths per 10^6 tonnes of mined coal. In large modern mines, the rate is likely to decrease by 50%, i.e. 0.2 deaths per 10^6 tonnes (Hamilton, 1977; Morris et al., 1979). In surface mining, the accident fatality rate has been estimated to be 0.1 deaths per 10^6 tonnes of coal. The rate of accidental non-fatal disabling injuries in underground mining is estimated to be 30 per 10^6 tonnes of mined coal, while in surface mining it is estimated to be 5.5 per 10^6 tonnes (Morris et al., 1979). Table 4 gives the estimated number of fatal and non-fatal accidents resulting from coal mining per 1000 MW(e)y. It should be noted that statistics from other countries might show different accident rates and the estimated number of fatal and non-fatal accidents per 1000 MW(e)y could be higher or lower than these figures.

Table 4. Estimated fatal and non-fatal accidents from coal mining (per 1000 MW(e)y)**

	Underground Mining	Surface Mining
Fatal accidents	1.20 (0.6)*	0.3
Non-fatal accidents	90 (45) *	16.5

* - Values between brackets are estimates for large modern mines

** - Assuming that 3×10^6 tonne coal (energy content 2.6×10^7 Btu/tonne are required for the production of 1000 MW(e)y from a power plant with 38% thermal efficiency.

26. Occupationally induced mortality and morbidity (due to respiratory diseases, especially black-lung disease known as coal worker's pneumoconiosis, CWP) in coal miners is subject to great uncertainity. It was estimated (New York Acad. Sci. 1971) that 25% of coal miners get black-lung disease from ingestion of coal dust. However, in many countries, stringent control measures have considerably reduced the incidence of the disease. Rae (1971) estimated that CWP might be virtually eliminated by reducing dust concentration in underground mines to 2 mg/m^3. However, this may not be possible for techno-economic reasons, or in some coal mines especially in developing countries.

27. In a recent study in the U.S.A., Rockette (1977) estimated the occuptaional disease induced-mortality in underground coal mining at 0.07 deaths per 10^6 tonne. Morris et al.,(1979) considered this figure as the best estimate, with a range of zero to 0.47. The chronic respiratory disease incidence has been estimated to be about 12 times that of deaths (Morris et al., 1979). Using these estimates, the calculated number of occupational deaths per 1000 (MW(e)y would be 0.21 (range between 0 and 1.41). The calculated number of cases of chronic respiratory disease is 2.52 per 1000 MW(e)y.

28. Some studies have been made on the relationship between trace elements in coal and the severity of CWP (Sweet et al., 1974; Carlberg, 1971). No relationship has been found between the severity of CWP and means of chromium, copper, iron, manganese, nickel, titantium, zinc and non-coal dust. However, vanadium was found to be more strongly associated with CWP than either beryllium or magnesium. A 1975 survey of the presence of radon-222 and radon-220 daughters in 123 operating mines in the U.S.A. concluded that there was no apparent occupational health hazard from inhalation of radon-222 or radon-220 daughters (Lee et al., 1975).

29. The incidence of CWP in surface coal mines is much lower than in underground mines. Fairman et al. (1977) found that 4% of 1438 surface miners had some evidence of CWP, but only 7 miners (0.5%) had X-ray films interpreted as CWP. Most of these had previously worked in underground mines for prolonged periods.

30. Another occupational hazard in coal mining is noise produced by mining equipment. A survey made in 1976 in North-Rhine Westfalia (FRG) showed that about 61% of workers in underground mines were exposed to a maximum noise level of 90 dB(A) which is considered non-injurious according to present regulations in the FRG, about 31% were working at noise levels of 91-100 dB(A) and about 8% of the workers exposed to 101 dB(A). Recently, several technologies have been applied leading to marked reduction in the level of noise of some of the mining equipment (Hurck, 1978).

Impact of Coal Mining on Land:

31. Surface coal mining (strip mining) has a more serious impact on land than underground mining. The amount of disrupted land varies from one place to another, depending on the geological occurrence of the coal-bearing formation and its characteristics. It has been estimated in Poland, for example, that 6-9 hectares of land are disrupted in the production of one million tonne of lignite (ECE, 1976). In other countries, as much as 800 hectares are disrupted per one million tonne of mined coal.

32. Where surface mining is carried out in densely populated areas (for example, in the Rhineland, Federal Republic of Germany) it has a direct effect on human settlements and the total infrastructure in the area. Construction of new settlements, roads, etc., is necessary if mining operations are to move towards older inhabited areas. Reclamation of strip-mined areas has been successfully achieved in some countries. In the Rhine area, for example, huge wheel excavators selectively strip off and save the top layer of loess (an extremely fertile type of loam), and remove the remaining sand, gravel and clay overburden to expose the coal beds. Simultaneously, mammoth spreader machines fill the overburden back into mined-out pits while bulldozers level it out in preparation for applying the top layer of loess (Nephew, 1972). Fields of grain and hay are already thriving on land that was restored less than five years ago.

33. The degree of difficulty and the time required for the land to be restored depends to a large extent on the grading of the land after mining, soil restoration, fertilizer addition, the amount and type of reseeding, and the amount of rainfall and water available in the area. The water needs for reclamation vary from 1500-12000 m^3 per hectare per year. The amount and type of treatment to obtain satisfactory results will vary from place to place as will the costs. It is possible, in spite of the great variability, to generalize on the range of costs that may be involved in restoring strip mined areas. The complete restoration conducted in the German Rhineland brown coal region is estimated at $ 7500 to $ 11,000 per hectare, and about $ 10,000 per hectare for the UK; costs estimated for the U.S.A. vary between $ 250 and $ 10,000 per hectare depending on the degree of reclamation used. Generally speaking, about 4% of the coal production costs are required for reclamation of land (OECD, 1978). In some areas, coal mine spoil has been used for brick manufacture, cement and light-weight aggregate production (Glover, 1978).

Impact of Coal Mining on Water:

34. Coal-mining water demands are modest, and include water for dust control, fire protection and coal washing. Average water use in coal mining varies from 63 to 120 litres per metric ton in underground mining and about 17 litres per tonne for surface mining. An additional 33 litres per tonne in both methods are required for waste disposal (UNESCO, 1979). Underground mining has little direct impact on surface streams but may have profound long-term effects on ground water resources. By its nature a mine tends to drain a large area, and if soluble minerals are present in the coal and associated rocks, these minerals may enter the streams draining a mining region and cause severe degradation of the water quality. This effect is important both where mines are drained by pumping and in mountainous regions where drainage is by gravity. Contamination caused by both deep and surface mining has substantially altered the water quality of some 17,000 km of streams in Appalachia, U.S.A. Acid drainage seriously pollutes about 10,000 km of streams, reducing or eliminating aquatic life (Nephew, 1972).

35. Different control measures are being taken in different countries to minimize the detrimental effects of acid mine drainage. Such measures include drainage control in the mine area, proper disposal of sulphur-bearing materials to ensure that pyritic refuse does not come in contact with water, sealing up abandoned mines to prevent water from entering the sulphur-bearing soil and chemical treatment of acid mine drainage. The latter consists essentially of treatment with various alkaline neutralizing agents, including limestone, lime, and caustic soda. Such treatment is designed primarily to treat solution acidity and remove those ions whose solubilities are sensitive in the acid to neutral range. New methods of treating acid mine drainage utilizing ion-exchange technology, reverse osmosis, and flash distillation reduce acidity and a substantial part of the dissolved ions. In some countries, stringent control measures are being implemented to avoid the hazards of acid mine drainage.

Environmental Impacts of Coal Processing

36. Coal cleaning is accomplished by physically separating refuse and sulphur-containing pyritic material from coal. Chemically-bound organic sulphur is not removed. These physical beneficiation techniques are capable of removing up to 40-50% of the sulphur and 65-75% of the ash contained in the raw coal (Ferrell, 1978). The amount of pollution generated in the process of coal cleaning depends upon the amount of coal treated, the chemical and physical properties of the coal, and the top size to which the coal must be prepared.

37. Most air pollution arising from coal washing is the result of drying of the coal in a stream of hot combustion gases that are produced by the burning of coal. The air pollutants that are created are fine coal dust, ash, NO_x and SO_x, resulting from the combustion of the coal used to supply the hot gases for coal drying. In addition, dust is created during the crushing and grinding of the coal to the size required. Air pollution can also arise from burning of refuse piles at coal preparation plants which have caught fire as the result of spontaneous combustion. This can usually be controlled by preventing oxygen from leaching the carbonaceous material by reshaping the pile to avoid steepy sides and by covering the pile with soil and vegetaion.

38. Coal washing requires varying amounts of water depending upon process and type of coal (UNESCO, 1979). The liquid effluent produced is called black-water and contains suspended coal fines. Black-water is usually sent to a tailings pond where the solids are allowed to settle and the clear water re-circulated. Re-circulation and treatment of wash water are integral parts of the operation of modern coal cleaning plants. Closed water circuits have grown in popularity because they eliminate discharge to streams, reduce makeup water, and allow for improved recovery of fine coal.

39. Solid wastes from coal cleaning and processing consist of coarse and fine refuse and constitute a potential source of acid mine drainage. The finely divided and well-exposed state of coal refuse enables acid-producing and weathering processes to work more effectively. Pollution from refuse piles can be controlled by proper reclamation to prevent seepage or by diverting any seepage from the piles to settling ponds where suspended solids and other pollutants can be retained and treated.

40. The occupational accidents in coal processing have been estimated at 0.02 deaths per 10^6 tonne of coal input to the plant and 1.3 disabling injuries per 10^6 tonne (Morris et al., 1979). Accordingly, 0.08 deaths and 5.2 dissabling injuries may be incurred per 1000 MW(e)y.

Environmental Impacts of Coal Transportation and Storage

41. Inland coal transportation is generally by railway or inland waterway over long distances, by conveyor belt or road over shorter distances, and in the future will be increasingly by slurry pipelines. The principal environmental impact of surface transportation of coal is the fugitive coal dust, unless measures are taken to eliminate or substantially reduce its occurrence. A surface pipeline might create a barrier to animals and farm equipment, thereby creating possibly greater secondary impacts than railways.

42. The principal pollutant from loading/unloading, and transportation, and storage of coal is fugitive coal dust. It is estimated that about 0.1 per cent of coal are lost during transit and the loading/unloading operations (OECD, 1978). The amount of dust generated from the open storage piles varies widely depending on such factors as climate, topography, and characteristics of the stored coal. Dust from coal handling and open coal storage can be suppressed by different methods, for example by sparying, storing in enclosed bins or silos, etc. Water used in coal slurry pipelines is contaminated with suspended and dissolved solids and may cause water pollution problems if discharged without proper treatment.

43. The storage of any coal can present problems of spontaneous combustion from reactions between the coal and atmospheric oxygen at ambient temperatures. This is especially true in case of lower rank coals with high proportion of volatiles. Special precautions are generally taken to prevent such spontaneous combustion.

44. The accidental fatality rate in railway transport (based on statistics for rail freight transport in the U.S.A., see Morris et al., 1979) has been estimated at 0.01 per 10^6 tonne of coal transported over a haul distance of 500 km, while in waterway transport by barge, it is estimated at 0.04 death per 10^6 tonne of coal. For pipeline transport, accidental death is 0.005 per 10^6 tonne of coal over a 500 km distance. According to these estimates, the calculated fatalities from coal transportation per 1000 MW(e)y would be:

Railway transport of coal	0.03
Waterway transport of coal	0.12
Pipeline transport of coal	0.01

It should be emphasized that these values differ markedly with distance of transportation and are lower for shorter distances. Some countries, for example, the U.S.S.R., have introduced the concept of "energy parks" or complexes where the power plants are located near the coal mining and cleaning plants. This makes it possible to reduce the environmental impacts of transportation of coal and to better manage the wastes resulting from all plants. The U.S.A. and other countries are considering this concept. In such cases, however, the electricity generated from these centralized complexes has to be transmitted through long transmission lines to centres of consumption (see Chapter VI, for environmental impacts of transmission lines).

Environmental Impacts of Coal Utilization

Traditional Coal Combustion:

45. Coal is used directly at home, in industry, agriculture or for electricity generation. The percentage of coal used in the different sectors varies considerably from one country to another.

46. Direct combustion of coal has a number of environmental impacts due to the emission of air pollutants (sulphur oxides, SO_x; nitrogen oxides, NO_x; carbon monoxide, CO; carbon dioxide, CO_2; particulates; organic compounds; trace metals; radionuclides; etc.) and the creation of an ash waste which requires disposal. These problems are particularly evident in the power industry where large quantities of coal are burned.

47. When coal is burned, sulphur in the coal is oxidized mainly to sulphur dioxide (SO_2) but very small amounts of sulphur trioxide are also produced. Some proportion of the sulphur always remains with the bottom ash as sulphate and a small amount is retained as sulphate in the fly ash. Generally about 5% of the sulphur in hard coal is retained in the bottom ash and about 95% is emitted as SO_x, although there can be a greater retention with lower combustion temperatures.

48. The quantity of fly ash or particulate emissions is determined by the ash content of the coal, the temperature of combustion and the design of the boiler. Fly ash is generally formed by evaporation and subsequent condensation of ash matter, or by elutriation of solid or molten ash particles by the moving gases. The former mechanism leads to the formation of very fine particulates, often less than one micron in diameter, which are difficult to remove from the flue gas. Higher combustion temperatures produce more fine particulates. Technology is well developed for the control of particulates above the domestic use level. Domestic control is often applied in urban areas by requiring the use of specially prepared smokeless solid fuel.

49. The formation of nitrogen oxides (NO_x) during combustion is a complex mechanism which depends upon temperature of combustion, design of the combustion chamber and availability of excess combustion air. During

combustion both the nitrogen in the fuel and the nitrogen in the air can be converted to NO_x. In larger combustors, the temperature of combustion is higher and NO_x formation is greater. NO_x formation can be controlled to some extent by controlling the excess combustion air or by certain modifications to the combustor.

50. Table 5 gives an estimate of the airborne, liquid and solid wastes produced by a coal-fired power plant. The characteristics and impacts of the different pollutants on the environment are discussed in detail in Chater V.

Coke Production:

51. Coking is the process of heating coal in an atmosphere of low oxygen content, i.e., destructive distillation. During this process organic compounds in the coal break down to yield gases (coal gas) and a residue of nonvolatile nature (coke). The gases are drawn off to a collecting main and are subjected to various treatment to separate ammonia, coke-oven gas, tar, phenol, light oil and pyridine. The collected coke-oven gas, being high in CO and hydrocarbon content, is used as a fuel in the coking process and in the steelmaking process. Hydrogen and carbon disulphide present in the gas are emitted as sulphur dioxide during combustion. Desulphurization of coke-oven gas prior to combustion is carried out in a number of countries, notably in FRG and Japan.

Table 5. Effluents from a coal-fired power plant (per 1000 MW(e)y) in tonne*

Airborne Effluents	
Particulates	3x10^{3}
Sulphur oxides	11x10^{4}
Nitrogen oxides	2.7x10^{4}
Carbon monoxide	2x10^{3}
Hydrocarbons	400
Liquid Effluents	
Organic material	66.2
Sulphuric acid	82.5
Chloride	26.3
Phosphate	41.7
Boron	331
Suspended solids	497
Solid Wastes	
Bottom ash + recovered fly ash	3.6x10^{5}

* Calculated from data given by Wilson and Jones (1974). Assuming power plant burns 3x10^{6} tonne coal; sulphur content of coal 2%; energy content of coal 2.6x10^{7} Btu per tonne; thermal efficiency of power plant 38%; fly ash removal efficiency 99%; no flue gas desulphurization.

52. Water and tar vapour in the gases emitted from the coking process condense as the gases are cooled. The water is then separated from the tar in continuous decanters. This water, called ammonia liquor, is by volume the second largest product from coking. It contains phenol which, even when present in very minute quantities, constitutes a real threat to water purity. The total amount of phenol-carrying water discharged may be of the order of 130 to 180 litres per tonne of coal. Up to 98-99 per cent of the phenols can be removed by existing liquid extraction processes (OECD, 1978).

Coal Conversion Processes:

53. The concept of coal conversion is deceptively simple. It involves primarily two basic steps: the cracking of heavy hydrocarbons into lighter ones and the enrichment of the resultant molecules with hydrogen. Unlike the concept, the application of coal conversion is not simple. It involves the handling of enormous amounts of a highly variable material (upwards of 25,000 tonnes of coal per day) often at high temperatures and pressures; it requires containment and control of both highly corrosive process materials and those that pose a possible health threat; and it calls for treatment and disposal of a voluminous solid waste and a possibly hazardous liquid or gaseous waste (Braunstein et al., 1977). Nonetheless, coal conversion is a viable technology.

Coal gasification:

54. Low-Btu and high-Btu gases are the products of prime interest in coal gasification. Low-Btu gas (heating value of 100-500 Btu/scf or 3700-18500 kJ/m^3) is usable as fuel feedstock or for power generation in combined gas-steam turbine power cycles. High-Btu gas (heating value of 900-1000 Btu/scf or 33300-37000 kJ/m^3) can be a substitute for natural gas and would find wide use for heating fuel and industrial feedstock. The basic difference between low-Btu and high-Btu processes is that air is used instead of oxygen in the gasifier to produce low-Btu gas. Also, the shift conversion and methanation operations are not used in low-Btu gas production. Most gasification technologies under development today incorporate the concept of hydrogasification in which the incoming coal is initially reacted with a hydrogen-rich gas to form directly substantial amounts of methane.

55. The rates and degrees of conversion of the various reactions that take place in gasification are functions of temperature, pressure, gas composition, and the nature of the coal being gasified. Aside from the various operating configurations used, most gasification systems can be categorized according to the following methods of contacting gas and liquid streams: suspension-or entrained-bed reactor; fixed - or moving-bed reactors; fluidized-bed reactor, and molten-bath reactor (OECD, 1977; Braunstein et al., 1977).

56. Although coal gasification was carried out on a commercial scale in the 1930s and 1940s, the technology was abandoned when a cheaper natural gas and oil became abundant. At present, revival of interest in coal gasification, especially in inudstrial countries, is based on the expected need to find a substitute to restrict oil imports. Several studies are underway to develop technologies for coal gasification with reasonable costs to increase the conversion efficiencies.

57. In-situ gasification of coal, which converts a coal seam into combustible gases, produces a gas rich in carbon monoxide, carbon dioxide, hydrogen, hydrocarbon gases, and other gases. Depending on the gas injected (air, oxygen, or oxygen and steam), the heating value of the product gas can range from as low as 50 Btu/scf when air alone is injected to as high as 280 Btu/scf when an intermittent air-stream sequence is used (Braunstein et al., 1977). The idea of underground gasification is attractive. The method avoids mining and waste disposal and adds unaccessible, unworkable, or uneconomical coal deposits to the energy pool. Unfortunately, the gas has a low heating value and would either have to be used at the site or upgraded for transportation.

Coal Liquefaction:

58. Synthetic liquid fuels have a prime potential use in the firing of industrial and electric boilers and gas turbines. Advantages of coal liquefaction are that the entire range of possible products - including fuel oil, gasoline, jet fuel, and diesel oil - can be produced from coal by varying the type of catalysts and other operating conditions. This flexibility is very desirable from a process standpoint.

59. Industrial quantities of liquid fuels, suitable as a petroleum refinery feedstock, were produced in Germany in the 1930s-1940s by two different processes. In one (Bergius), the coal was dissolved in recycled oil and reacted in the presence of a catalyst with hydrogen (produced by the gasification of coal) at pressures of 700 atm. and temperatures of 450°C. The resulting liquid product was filtered, part of the oil recycled with fresh coal, and the balance of the primary oil product hydrogenated in a gaseous phase to make synthetic petroleum products. In the other process (Fischer-Tropsch), all of the coal was first gasified to a mixture of carbon monoxide and hydrogen. After purification and adjustment of the carbon monoxide-to-hydrogen ratio, the gas was reacted over a catalyst at moderate pressures (30-35 atm.) and temperatures (235°C) to produce liquid products. By the selection of different carbon monoxide-to hydrogen ratios, catalysts, pressures, and temperatures, a wide range of liquid products can be made - from straight chain hydrocarbons to alcohols. A commercial plant using the Fischer-Tropsch process is in operation today in South Africa. South Africa domestic coals are gasified in Lurgi generators, the resulting gas purified, and then liquefied by two different catalytic processes. The plant uses 6000 tonne of coal per day and produces a wide range of liquid products - gasoline, diesel and other fuel oils, waxes, alcohols, and ketones. The plant size is 8,000-10,000 barrels of oil per day (OECD, 1977).

Many of the new processes now being investigated to convert coal to oil are designed to produce a clean liquid product that can be used as a utility or industrial boiler fuel to raise steam or for use as a heat source for industrial processes. The objective is to have a product that is low in sulphur and ash and can be stored, transported and burned as a liquid.

Environmental Impacts of Coal Conversion:

60. Table 6 summrizes the estimated resource requirements and effluents for coal gasification and liquefaction. It should be noted that modern plants are designed for zero aqueous discharge, thus either avoiding water pollution concerns or reducing water intake requirements.

Table 6. Estimated resource requirements and effluents from coal gasification and liquefaction*

	Low-Btu Gasification	High-Btu Gasification	Coal Liquefaction
Resource requirements			
Coal (tonne)	$4.6x10^6$	$5.7x10^6$	$4.6x10^6$
Land use (hectare)	1531	672	1562
Water (litre/y)	$2.4x10^9$	$19.6x10^9$	$10x10^9$
Effluents (air-borne), tonne/y			
Particulates	0.75	820	529
SO_x	1960	9061	1706
NO_x	982	6771	7409
CO_x	28	356	291
Hydrocarbons	28	108	2268
NH_3	40	49	-
Solid wastes (tonne/y)	$53x10^4$	$57x10^4$	$62x10^4$

* Calculated after data given by EPA (1978), on the basis of energy requirements to produce 1000 MW(e)y; i.e. $7.9x10^{13}$ Btu/y. The energy content of coal assumed to be $2.6x10^7$ Btu/tonne.

61. Conversion processes are dually oriented: (1) to convert plentiful coal into scarce liquid and gaseous fuel and (2) to remove or treat, during processing, environmentally unacceptable or health-endangering compounds. As a result, coal conversion methodology is concerned as much with processes for handling the by-products as with the products themselves. Knowledge of wastes and emissions from coal conversion processes is still incomplete (Braunstein et al., 1977; Talty, 1978). However, it is known that wastes

will be generated during each main process stage and that these wastes are largely controllable or convertible to environmentally acceptable forms. A more serious and less tractable problem arises from possible fugitive emissions produced by inadequate containment of process streams (leaky valves) or incomplete treatment of wastes. High-temperature process streams may contain carcinogenic organic compounds similar to those implicated in an increased incidence of skin and lung cancer among coke-oven workers.

62. Because coal is a dirty fuel, early technologies that used coal without sulphur-emission control contributed heavily to environmental pollution. Coal conversion, however, is specifically mandated to produce clean fuel from coal; thus, a wide variety of techniques for removing sulphur are integrated into coal conversion processes. Sulphur can be removed during coal pretreatment or the conversion process and from product and waste streams. Because organic sulphur is difficult to remove during coal pretreatment and because about 90% of the organic sulphur is converted to hydrogen sulphide in both gasification and liquefaction, this form of sulphur is estimated to be the major sulphur contaminant in gas streams. Most of the sulphur in coal is expected to be recovered from conversion streams as elemental sulphur, although the sulphur that reaches the stack gas as sulphur oxides and is collected by limestone scrubbing will end up as sulphate. Neither form of sulphur is particularly obnoxious environmentally, although the quantity to be disposed of is considerable: A 25,000-ton-per-day plant using a coal containing 4% sulphur will produce 1000 tons of sulphur daily. As opposed to throwaway disposal, new uses for elemental sulphur are being considered. Production of sulphur-based paving materials and plastics or use of sulphur in thermal and acoustical insulation are considered alternatives to landfill or minefill disposal (Braunstein et al., 1977).

63. The fates of trace elements during the coal conversion process are not yet completely known; however, the majority of elements are expected to remain in the solid by-products such as ash, chars, and filter cake. Nontheless, material balance studies are required to trace the pathway of hazardous elements during conversion and to determine the concentrations and forms of the elements in gas streams, condensates, and waste streams. The release of conversion process wastewater into natural waters also constitutes a possible source of environmental pollution. The aqueous streams, which arise when process gases are condensed or scrubbed, may contain components of the product gas - carbon monoxide, carbon dioxide, hydrogen, hydrogen cyanide, and methane - along with contaminants such as sulphur and nitrogen compounds, ash (dust and particulates), phenols, emulsified tar, and oil. Fugitive tar collected in wastewater contains a wide variety of organic compounds, and wastewater particulates may collect and adsorb polycyclic aromatic hydrocarbons (PAH). Of the water-soluble organics, phenols appear to be important, along with alcohols such as catechol, resorcinol, and their methylated derivatives. Basic components such as pyridines, quinolines, and indoles have also been identified in product wastewater. The environmental impacts of these pollutants arising from coal conversion processes have still to be clearly defined.

CHAPTER III

OIL AND NATURAL GAS

64. Oil is undoubtedly the most versatile fossil fuel and source of energy. The distillation of crude oils produces a variety of refined products, from straight-run petrol, middle distillates (such as kerosene, heating oils, diesel oils and jet fuels), wide-cut gas oil (waxes, lubricating oils and starting material for the production of gasoline) to residual oils, usually asphaltic in nature. Modern transportation systems, the petrochemical industry and several energy-requiring systems cannot operate without these products. Indeed, oil has recently played a major role in the socio-economic structure of the world, not sharedby any other source of energy.

65. Table 7 gives the production and consumption of oil in the world. Over ten years (1966-1976), the production and consumption has nearly doubled. The annual change in 1976 over 1966 is about +5.6% (British Petroleum, 1977).

Table 7 - World Oil Production and Consumption (10^6 tonne)*

	Production			Consumption	
	1975	1976	1977	1975	1976
N. America	557.4	538.6	529.3	849.0	908.3
Latin America	228.1	233.0	236.0	174.0	186.4
W. Europe	30.6	45.0	68.0	664.0	706.4
Middle East	972.7	1100.1	1084.7	66.8	73.3
Africa	245.9	285.4	298.0	51.3	54.2
Asia	89.1	103.1	111.3	356.2	377.9
Oceania	19.9	20.5	22.7	35.3	36.3
USSR	485.0	515.0	538.0	362.0	380.0
Eastern Europe	20.0	20.0	20.7	86.0	90.0
China	65.0	75.0	93.3	55.6	66.0
Total World	2713.7	2935.7	3002.0	2700.6	2878.8

* After World Energy Supplies: 1972-1976, United Nations (1978); British Petroleum, (1977).

66. The estimated recoverable amounts of oil at the end of 1976 are given in Table 8. It should be noted that these estimates do not represent the potential of oil reserves in the world since exploration activities, particularly in the offshore and outer continental shelf areas, will probably lead to the discovery of huge oil reserves, hitherto unknown.

Table 8 - Estimated Oil Reserves in the World (proven, recoverable, in 10^6 tonne)*

N. America	5800
Latin America	4700
W. Europe	3300
Middle East	50000
Africa	8100
USSR	10700
Eastern Europe	400
China	2700
Asia	2600
World Total	88300

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* After British Petroleum (1977).

67. Although the oil production has been steadily increasing in the world, some studies (e.g. WAES, 1977) predict that the production will level by 1985 and then decline towards the end of the present century. It is difficult at this stage to draw decisive conclusions in this respect since the oil production is controlled by several factors, technical as well as geo-political.

68. Natural gas (also that associated with oil) is becoming an attractive source of energy, both to reduce dependence on oil and from the environmental point of view. Table 9 gives the world natural gas production and consumption for 1975-1977. Between 1966 and 1976, the production and consumption of natural gas has increased about 1.6 times (British Petroleum, 1977).

69. The estimated recoverable natural gas resources at the end of 1976 are given in Table 10. These values are, again, approximate values and do not represent the true natural gas potential of the world. Recent exploration operations have led to the discovery of several fields of natural gas (McCaslin, 1975), and further exploration efforts will lead to the discovery of more fields.

Table 9 - World Production and Consumption of Natural Gas (in $10^9 m^3$)*

	Production			Consumption	
	1975	1976	1977	1975	1976
N. America	622.5	627.9	641.1	644.0	654.1
Latin America	40.3	41.1	41.1	45.7	47.3
W. Europe	167.4	175.2	172.9	177.9	195.2
Middle East	41.1	41.9	43.4	31.2	33.6
Africa	11.6	16.3	16.3	6.8	7.6
Asia	22.5	26.4	27.1	21.7	25.8
Oceania	5.4	7.0	8.5	5.7	7.0
USSR	265.9	295.3	320.0	274.2	294.8
Eastern Europe	48.1	52.7	55.0	58.4	62.7
China	3.9	3.9	4.7	5.5	6.1
Total World	1228.7	1288.4	1331.0	1271.0	1334.0

* After World Energy Supplies 1972-1976 United Nations (1978); British Petroleum (1977).

Table 10 - Estimated Natural Gas Reserves at the end of 1976(in $10^9 m^3$)*

North America	8229
Latin America	2709
W. Europe	4272
Middle East	16077
Africa	6273
USSR	27540
Eastern Europe	300
China	750
Asia	3600
Total World	69750

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* After British Petroleum (1977).

Environmental Impacts of Oil and Natural Gas Production

70. Exploration and production of oil and natural gas, whether carried out on land or offshore, have a number of environmental impacts. Accidents and equipment failures can cause harm to workers and to the environment. Fires, explosions and accidental oil spills are the most common accidents. Modern drilling methods and equipment incorporate a number of safety measures which have been devised particularly to prevent accidents and if they happen, to minimise their effects (van Eek, 1977).

71. Exploration and production of oil and gas from offshore fields began about 100 years ago. In 1974, offshore areas produced about 1.2 million tonne of oil daily, or about 18 per cent of the worldwide crude production. Offshore proved crude oil reserves are estimated at 22 x 10^9 tonne and represent 23 per cent of the world total. The share of offshore petroleum in worldwide production is estimated to reach 25 to 30 per cent in 1980 and probably 35 to 40 per cent in 1990 (Leleuch, 1973). Table 11 shows the rapid increase in oil production from offshore wells.

Table 11 - Offshore Oil Production (10^6 tonne)*

	1970	1974
United States	74.1	53.9
Middle East	97.0	184.0
Venezuela	115.0	97.3
Others	59.1	100.0
Total	345.2	435.2

* Calculated after Outer Continental Shelf Assessment(1974)

At the present time exploration in offshore waters is taking place in more than 100 countries and in about 40, production of oil is about to take place. To date more than 18000 oil wells have been drilled off the US Coast alone (Westaway, 1977).

72. Offshore oil and gas exploration and production is a major industrial development. The support it needs in terms of installations and trained personnel is large and is provided from coastal areas as near to the oil fields as possible. When these areas are not industrialized, labour and housing shortages may become acute, and considerable pressure is put on social and other community services. The siting of the necessary facilities, e.g. pipeline terminals, platform building sites,...etc leads to some problems in land management as it competes with other possible uses for the coastal zone.

73. The fatality rate of accidents in onshore and offshore operations is of the same magnitude (EPA, 1978) and has been estimated at 0.02 per 10^6 tonne of oil produced and 0.18 per $10^9 m^3$ of natural gas produced (0.0002 per 10^6 tonne). The rate of injuries has been estimated at 1.72 per 10^6 tonne of oil and 16.5 per $10^9 m^3$ of gas (or 0.019 per 10^6 tonne of gas). The number of fatalities and injuries incurred by oil and natural gas production to produce 1000 MW(e)y has been calculated and are given in Table 12.

Table 12 - Fatalities and Injuries from Accidents in Oil and Natural Gas Production (per 1000 MW(e)y)

	Fatalities	Injuries
Oil*	0.50	43.0
Natural Gas**	0.40	36.3

* Assuming that 2.5×10^7 tonne of oil are needed as input to refinery producing 2×10^6 tonne of residual oil for the production of 1000 MW(e)y.

** Assuming that $2.2 \times 10^9 m^3$ of natural gas are required.

74. Despite careful treatment of effluent discharges and stringent controls to minimise the number of accidental oil spillage, offshore and terminal operations will result in some discharge to surrounding waters. Although some field studies (for example, in Lake Maracaibo, Venezuela, and Timbalier Bay, Gulf of Mexico) showed that there is no ecological damage in these areas due to offshore operations (Westaway, 1977), further studies are necessary to determine the long-term effects of hydrocarbons and trace elements on the marine ecosystem. Tidal marshes, coastal wetlands, river swamps and sheltered

bays which are sensitive eco-zones support a variety of organisms at all stages of development, and low levels of hydrocarbons may have some local long-term effects on these organisms.

75. Although accidental spills from offshore operations are normally of relatively small volume, some large spills have occurred. Blowouts and natural hazards (hurricanes, storms etc) are the main causes of such accidents. In the period between 1953 to 1972, 43 accidents occurred during operations on the outer continental shelf in the U.S.A. About 290,000 to 1 million barrels of oil were spilled and the accidents caused 56 deaths and 108 injuries among workers (OCS, 1974). Technology now available is sufficient to ensure a safe conduct of operations for depths down to 200 m and for climatic conditions similar or less severe than those of the North Sea. However, there is a definite trend towards working at greater depths and in even harsher environments. For this reason, new technologies are being continuously developed and there may be a possibility that higher environmental risks may occur when applying these new technologies (OECD, 1977).

76. In the production of oil (offshore or onshore) large amounts of brine (about $8 \times 10^7 m^3$) are associated with the oil in an emulsion form. The brine is separated by the aid of chemical agents or electrostatic separation. The disposal of the separated brine is normally carried out by injection into the earth. Small amounts may however be disposed of in the near-by marine waters or in other surface waters, in which case, it will seriously affect the water quality of the receiving water body and consequently the aquatic ecosystem.

77. If the oil and gas produced contain a high H_2S content, sulphur emissions will constitute a potential air pollutant at the production site. The amount of emitted sulphur depends on the storage technology of oil at the site before transportation, the sulphur content and the temperature of the crude during storage. In some cases, especially in gas production, desulphurization is necessary to satisfy the pipeline specifications on sulphur content. The recovery of sulphur depends, however, on techno-economic factors which include the availability for markets for sulphur. In small fields, the H_2S is vented into the atmosphere or flared. In large fields, however, Claus plants are used to recover sulphur from 85-95% of the H_2S; the rest being emitted to the atmosphere.

Environmental Impacts of Transportation of Oil and Natural Gas

78. Areas of production of oil and natural gas seldom co-incide with areas of processing and/or demand. Most of the crude oil and gas has to be transported over long distances between exporting and importing countries.

Marine Oil Transportation:

79. Marine transportation is the most important means of transporting oil from oil-producing to oil consuming areas. Table 13 shows the growth in the transport of oil by sea over the period 1960 to 1975, a period of rapid growth and one which has seen a major change in the size and technological development of tankers. During this period, the total oil transportation by sea more than tripled (the finished products nearly doubled while the crude movement has increased by a factor of more than 4).

Table 13 - World Movement of Oil by Sea (in million metric tonnes)*

	Crude	Products	Total
1960	305	144	449
1965	567	180	747
1970	1,033	230	1,263
1973	1,404	291	1,695
1974	1,387	269	1,656
1975	1,273	235	1,508
1977			1,700

* Source: Walder (1977); IMCO (1978)

80. To carry this oil, the world's fleet of tankers has also grown. In 1954 the world tanker fleet consisted of just under 3500 ships totalling 37 million deadweight tons (dwt). By 1977 there were nearly 7000 tankers in operation, totalling approximately 340 million dwt (IMCO, 1978). One feature of this expansion has been the great increase in the size of ships. The largest tanker in service in 1954 was around 30,000 dwt; today there are several ships of more than 500,000 dwt (ships over 150,000 dwt are referred to as Very Large Crude Carriers, VLCC; those over 350,000 dwt as Ultra-Large Crude Carriers, ULCC).

81. Although the world tanker fleet generally has a good safety record, the fact that ships today are so much larger than they were 20 years ago means that the consequences of an accident are potentially much greater - as was shown by the Torrey Canyon incident in 1967 and the even greater Amoco Cadiz disaster in 1978. Experience has shown that such incidents can have serious effect upon the environment and marine life, damaging such important resources as fisheries and tourism for long periods.

82. Tanker accidents can happen almost anywhere. While oil is imported chiefly into the industrialized countries of Europe, Japan and North America, tanker routes pass close to the coasts of many other countries. Winds and current can move oil slicks large distances in a relatively short time, and the consequences of a major spillage can be even greater in developing parts of the world, simply because there are fewer resources for dealing with them. Another danger to the oceans (and to coastal states) comes from the cleaning operations carried out by crews of oil tankers. The tanks in which the oil is carried are normally cleaned while the ship is returning to the loading port. In modern ships the normal procedure is to use special machines which blast jets of high-pressure water on to the tank sides removing the oily residues which are left after the oil has been unloaded. This procedure results in a mixture of oil and water forming at the bottom of the cargo tanks. Some of the tanks are also filled with water on the return voyage, to make the ship low enough in the water for it to be properly manoeuverable. The water used in this way also becomes contaminated with oily residues. In either case, the mixture of oil and water which results has to be disposed of before the tanker can take on a fresh cargo of oil, and in the past the normal practice was to pump this directly into the sea. For many years it has been recognized that the amount of oil being pumped into the sea is too great for the ocean to absorb; and a variety of methods have been introduced in an attempt to eliminate the problem of what is normally termed "operational pollution". The "load-on-top" (LOT) system and more recently the washing of tanks with crude oil have greatly reduced this type of operational pollution.

83. The In-Governmental Maritime Consultative Organization (IMCO) has played an important role in promoting safety at sea and reducing marine pollution from ships. IMCO has introduced a wide variety of international Conventions, Codes and Recommendations which have helped greatly in achieving these two objectives (see IMCO, 1978).

84. Table 14 gives the amount of oil spilled in the ocean due to tanker accidents, in the period 1970-1978.

Table 14 - Oil spilled into Ocean (tonne)*

Year	Oil Spilled
1970	190,450
1971	109,125
1972	58,500
1973	52,200
1974	54,900
1975	110,700
1976	135,000
1977	121,050
1978	237,600**

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* After IMCO (1979)

** Amoco Cadiz disaster contributed 220,000 tonne (Hann, 1979)

This amount of oil constitutes about 35% of all oil discharges in the sea (see Table 15).

Table 15 - Sources of Oil in the Oceans (after EPA, 1977)

Source	Estimated Contriburion (Barrels/y)	%
Production and Transport	16,000,000	34.9
Tankers		
Dry Docking		
Terminal Operations		
Bilges		
Accidents		
Direct Sources	6,500,000	14.3
Coastal Refineries		
Municipal Waste		
Industrial Waste		
Off-shore oil production		
Indirect Sources		
Rivers and Urban Runoff	14,000,000	31.2
Atmospheric fallout	4,500,000	9.8
Natural Sources	4,500,000	9.8
Seepage		
TOTAL	45,500,000	100.0

85. The ecological impact of oil transportation often arises more from the development and maintenance of loading and unloading facilities on shore than from the transportation medium itself. Terminals are often constructed in or near ecologically sensitive coastal areas, such as estuaries. The installation may alienate valuable nursery grounds for fisheries. Whether the terminals service a large petroleum refinery or a pipeline for conveyance of oil to distant places, the risk of an oil spill always exists in the transfer of oil from the tanker to the shore facility. Even in the absence of any acute, large-scale oil spills, there is often the long-term chronic effect of continuing small spills and leaks. Thus one might conclude that the interface between different media such as land and water, where the mode of transport must be changed and the substance must be transferred to accommodate this change, is the most vulnerable to transportation impact. In this respect, increasing attention has been paid recently to the selection of sites for deep-water oil ports. An

environmental risk index for the siting of deep-water oil ports has been developed recently for the east coast of Canada (Canada, Dept. Fish. and Environ., 1976). A similar activity is currently underway for site selection on Canada's west coast, where there is a need to have a terminal that would accept crude petroleum conveyed by tanker from Valdez, Alaska, and transmit it through a pipeline to areas of high demand in midwestern and southern U.S.A.

Impacts of Oil on Marine Environment:

86. Petroleum is composed of a large number of components ranging from the gaseous methane to the solid paraffins. The large majority of these compounds are hydrocarbons which are immiscible with water and are chemically inactive compounds. Lower alkanes (paraffins) are rapidly lost by evaporation and are the most readily biodegradable group. Aromatics are the most soluble, can be photodegraded and are the most toxic components of the oil. In general, smaller molecules in each fraction are more toxic and more volatile than the larger molecules, hence the low toxicity of weathered as compared to fresh crude. The composition of crude oil depends on its origin. There are heavy crudes (high content of large hydrocarbon molecules), and light crudes (high content of small hydrocarbon molecules); they may contain much sulphur (Kuweit 2.4%) or be "sweet" (North Sea with about 0.3% S). Refinery products, e.g. petrol, kerosene, diesel oil, residual oil, have more homogeneous compositions and some of them are far more toxic than the crude from which they were derived.

87. Spilled petroleum, following release to the oceans, spreads over surface waters. The extent of spreading depends upon the nature of the material and the prevailing wind and current systems. At this time, physical, chemical and biological processes begin which alter the composition of the oil which, because of its immiscibility with water, is initially present as a separate phase. Although the rates and degrees at which changes take place in the environment are not known in detail, the general directions can be predicted with some degree of certainty (Goldberg, 1976). The greater the rate and extent of spreading, the greater the rate of evaporation which will eliminate about 50% of the hydrocarbons. The low molecular weight hydrocarbons will dissolve in the water column; the rate of solution depends on wind, sea agitation and water temperature. Emulsions (chocolate mousse) form as semi-solid lumps containing up to 80% water. Biological, chemical and photo-oxidation processes tend to increase the solubility of some compounds.

88. There is a wide variety of marine ecosystems which could be affected by marine transportation of oil. Some ecosystems are more sensitive than others to the environmental changes that arise from marine transportation activities and facilities development. Clearly, the many physical processes in the sea leading to dilution and dispersion of pollutants, along with renewal of water, vary from place to place, depending on such factors as geographical configuration, exposure to oceanic currents, winds, tides and runoff. Perhaps the most critical consideration in terms of ecological impact of marine transportation is the effect on biological productivity. In this respect, coastal ecosystems are by far the most vulnerable, because they are generally the most productive and because the impact of an oil spill, for example, can be most severe at the water/land interface.

89. The latitudinal effect must be recognized when dealing with pollution or environmental problems of marine transportation. The higher metabolic rates associated with the higher temperatures of tropical and sub-tropical regions means that the restorative capability of ecosystems in such areas is higher than that of cold-climate ecosystems. By the same reasoning, arctic ecosystems heal slowly when injury is inflicted on them by pollution or other man-made activities. Oil spills and their adverse effects in the arctic can endure for a long time, particularly if the oil seeps under the ice or mixes with ice and snow. Bacterial degradation of oil slows down considerably at these low temperatures.

90. Coastal zones are generally more sensitive to oil pollution than the open ocean. The major world fisheries are located in the coastal zone; 90% of the world fisheries are produced in waters of the continental shelf which constitute only 10% of the ocean area (Waldichuk, 1977). It is here that not only the major groundfish stocks are located, but stocks of certain pelagic species are fished and crustacean and molluscan shellfish are harvested. The coastal waters are spawning and nursery areas for most species of demersal fish, such as cod and halibut, and for such pelagic species as herring. In some coastal waters, herring may deposit their spawn on intertidal vegetation and other substrate, rendering such areas extremely vulnerable to oil pollution. Anadromous species, which comprise an important component of commercial fisheries in some parts of the world, must pass through the coastal zone in their migration to riverrine spawning grounds as adults and out to the high seas as juveniles.

91. Invertebrate species and some pelagic fishes, which use the intertidal zone for spawning and rearing of larvae and juveniles would be particularly affected by an oil spill impinging on the shoreline. If intertidal animals are not suffocated by a layer of oil covering the inshore substrate, it can be almost certain that their flavour will be

impaired and acceptability on the market downgraded. It is usually the practice of regulatory agencies to close fisheries in areas thus affected, until it can be assured that the quality of fisheries products is acceptable for human consumption. Shorelines adjacent to oil transportation routes are always threatened by oil spills, because they are often at the mercy of onshore winds and tidal currents that can quickly bring an oil slick onshore.

92. Perhaps the most vulnerable of coastal ecosystems is the estuary. All kinds of physico-chemical and geochemical reactions take place there when freshwater mixes with sea water. The net result of such interaction is a unique type of ecological system. The estuary is often considered to be the most productive of coastal habitats. Estuaries provide nursery grounds for juvenile salmonids prior to these young fish continuing their journey out to sea. Certain micro-invertebrates serve as food for these juvenile fish, and any adverse effect on the food chain involving these organisms can have an impact ultimately on the commercial and recreational fisheries.

93. Although the normal surface flow in an estuary is seaward, because of freshwater input from the river, other physical characteristics of an estuary tend to present a situation where a pollutant like an oil slick can pose a threat. Tides and winds can combine with the geographical configuration of the coastline, for example, to move an oil slick into an estuary. There is little question that a large oil spill in an estuary can lead to acute ecological effects with possible long-term consequences. The chronic effects of small spillages and leaks of oil from a loading/unloading facility into an estuary would have little dramatic effect like a large-scale spill, but could lead to rather insidious long-term degradation of the estuarine ecosystem.

94. The character of the coastal land, where terminals are located, has a bearing on the environmental impact of a marine transportation system. The alteration of an estuary, in construction of a port,in general, and its back-up facilities, may have a profound effect on the ecology and use of the estuary by fish and other aquatic organisms. Dredging and filling can destroy benthic habitats for fishes and invertebrates and marshes for avian wildlife. Diversion of water flow in either a river as it enters the sea, or in coastal tidal currents, can modify various physical and chemical characteristics of the waters in the estuary and in the nearshore marine regime.

95. The marine environmental effects of oil pollution are regularly reviewed in various fora (Hoult, 1969; Cowell, 1971; NAS, 1973, 1975; Peters, 1974, Wolfe, 1977; GESAMP, 1977; API, 1977; BIO, 1977). Many collective and individual studies and reviews have been reported (GESAMP, 1977; Vernberg, et al., 1977; Wolfe, 1977; Malins, 1977; Cowell, 1976) on the subject. A number of factors must be taken into

consideration when assessing the impact of an oil spill. Oil is far from being a unique chemical compound with specific physical and chemical characteristics. Because of the inherent properties of oil which cause it to float on the sea surface, oil tends to become deposited in the intertidal zone once an oil spill reaches the shoreline. This has many undesirable consequences, one of which is that the aesthetic and recreational value of a beach is at least temporarily impaired. This effect can be counteracted by the application of suitable surface treatment agents for the protection of shorelines from oil spills. Also, sinking agents have been used in some oil spill cleanups to deposit the oil on the sea bottom before it reaches shore. In locations, where ecologically sensitive areas are threatened, emulsifying agents are used to disperse the oil in the water.

96. Oil that coats shorelines may persist for a long time, depending on the characteristics of the hydrocarbons. Crude oil and bunker C form tarry-like residues that may remain imbedded in beach sands or encrusted on rocks for months or even years. Weathering combined with the scouring action of waves eventually removes these residues. The lighter refined oils will usually evaporate without leaving the same type of persistent black residues. Depending on whether a beach is intensively washed by wave action or not, one beach may be more rapidly cleansed than another of hydrocarbon materials. Tarry residues may persist for a considerable time if oil is deposited out of the reach of waves until bacterial decomposition and other weathering processes break them up. Tarballs are found along shipping lanes in many parts of the world oceans.

97. The lethal effects of oil (refined oil is more toxic than crude oil) depend on its concentration and on the length of time an organism was exposed to it. Experiments with oysters showed that whereas they did accumulate more hydrocarbons in their tissues with time of exposure to oil the oysters, once they were placed in clean flowing seawater, they purged themselves rapidly of the accumulated hydrocarbons. After about 2 weeks in clean water, only negligible hydrocarbon levels were found in the oyster tissues, and there was no evidence of pathological damage to the oyster as a consequence to the oil (Mertens and Allred, 1977). Experiments with shrimp, clams and some other marine organisms produced similar results. Planktonic eggs and larvae may be particularly exposed and sensitive to oil pollution especially to light refined oils. Kerosene-based dispersants with high aromatic content are especially dangerous in this respect and this type of dispersant has, therefore, been banned in many countries.

98. Subtidal and intertidal benthic organisms have suffered particularly heavy losses from dishcarges of light and heavy oils and their subsequent treatment. The long-term ecological effects of oils and dispersants on these communities are the most extensively studied and documented. Complete recovery may take several years and, therefore, the effects of repeated oilings are particularly important. In the intertidal zone, mortality of grazing invertebrates such as sea urchins may result in an

explosiion of the population of attached green algae, which, in turn, affects other parts of the ecosystem. This type of secondary effect, is an aspect that has to be considered when damage due to oil is evaluated. A special case is offered by coral island ecosystems. If the corals are killed, the natural protection of the island from erosion will be lost. Further, because of isolation, most of the organisms in the coral island ecosystem will not be replaced. This would considerably prolong the duration of the effects even if the oil itself disappears or is removed.

99. The introduction of hydrocarbons to a population of marine bacteria selects those capable of utilizing this food source at the expense, at least initially, of the rest of the population. Evidence that low concentrations of crude oil and oil components inhibit bacterial chemotaxis has been questioned. It is noted that the number of micro-organisms able to use oil hydrocarbons as a source of carbon and energy increases from clean to oil polluted marine areas. This can be observed in inshore waters as well as in the open oceans.

100. Susceptibility of micro-algae appears to vary enormously. In addition, effects of an exposure may take a long time to become apparent and may even be the result of a comparatively short exposure. Laboratory studies have indicated that very low concentrations of oil may stimulate primary production by phytoplankton, but that higher concerntrations lead to reduction of carbon fixation, and finally to mortality. Other studies indicated that macro-algae, if coated with oil, may be mechanically stripped from their substrate (Waldichuk, 1977). Some lower forms are resistant to oil pollution and thrive in polluted environments. Low concentrations of oil have been shown to depress the growth of red-algae sporelings. Experiments appear to show that higher levels of oil inhibit biosynthesis of nucleic acids and their polymerization of macro-algae. Oil penetrates the higher forms of plant life, blocking intercellular spaces, increasing respiration and decreasing transpiration rates and affecting flowering and reproduction. It should, however, be borne in mind that these findings are the results of laboratory tests which may differ significantly from the actual behaviour of plants and animals in their natural environment.

101. Some littoral or salt marsh plants may tolerate repeated light oilings but heavy fouling oftern leads to mortality. These effects may take several years to appear. Mortality of some zooplankton species, including pelagic fish larvae, occurs from oil slicks at sea, with unknown ecological significance.

102. The combination of the variety of sublethal responses of marine organisms to crude and refined oils and their ecological implications are not fully understood. Effects of oil should be studied at the ecosystem level, rather than by single species bioassay. Attention should be paid to chronic and sublethal effects using, for example, histopathological techniques. Genetic alterations and other effects on single species should not be ignored.

103. Birds are particularly vulnerable to oil spills, whether they occur at sea or close to shore. Heavy mortality due to oil pollution of species with low annual breeding rates, such as auks, may have serious consequences. Populations of birds from discrete breeding colonies may be similarly seriously reduced or destroyed. When their inner feathers are coated with oil, insulation is lost, and a bird may die of exposure in any season. A total bird population is small compared to aquatic populations and runs a higher risk of extinction by whatever cause.

104. When an oil spill occurs, several options exists to deal with it:

(a) leave it,
(b) contain and remove it,
(c) disperse it,
(d) burn it, or
(e) a combination of these.

105. Selection of the most suitable technique, or techniques, depends on the circumstances of each spill, involving consideration of the scale of the spill, its location, the prevailing and predicted weather, the proximity of sensitive areas and the availability of oil spill clearance equipment and manpower. The decision-making processes to clean-up each spill should include the ecological interests (fisheries, wildlife, etc.), the commercial interests (tourism, etc.), the legal interests (plant and oil owner), the financial interests (insurance broker etc.) plus representatives from the State and authorities affected, together with technical assistance and advice of specialists trained in clean-up activities. It is important that the decision-making should be paid and flexible.

106. The cleaning-up operations can be complicated by sea and meteorological conditions. For example, because of rough sea conditions, the crud oil spilled by Amoco Cadiz in 1978 (off Brittany coast, France) was quickly emulsified with sea water as it leaked out of tanks. The resulting chocolate mousse, containing up to 80% water, became more and more viscous, resulting in pollution four times the initial volume of crude oil (Bocard et al., 1979). The costs of cleaning-up of oil spills varies from one place to another, but on the average it is estimated to $1000/barrel. (EPA, 1978).

Pipeline Transportation:

107. Oil spills can also occur during the transportation of oil by pipelines. Records of such land spills show that the most important cause is damage to the pipelines. Pipelines which are not buried in the ground can cause disturbances to wildlife and to some extent to land use in certain areas. The Trans Alaska Pipeline, for example, was examined for its possible impact on the permafrost, migrating wildlife, seismic exposure, etc. The route and design of the line was selected with a veiw towards minimising its overall impact on the environment.

Transportation of Natural Gas:

108. Natural gas consists of the short-chain hydrocarbon compounds (e.g. methane, ethane, propane and butane) and is usually transported from the well head to treatment facilities and ultimately to the consumer by pipelines. Until recently these pipelines followed overland routes; the growing production of natural gas in offshore areas necessitated, however, the commissioning of submarine pipelines, e.g. in the North Sea. In liquid state, natural gas (LNG) is transported by special tankers.

109. The natural gas is liquefied cryogenically at a temperature of -162°C (Tanner, 1977). Before liquefaction, the gas must be dried heavier hydrocarbons fractions removed and pre-treated to remove such components as H_2S, CO_2 and organic sulphur compounds that would solidify during liquefaction. Traces of mercury are sometimes present in natural gas which have to be removed because they may cause corrosion. The main environmental effects of a natural gas liquifaction plant are: (1) discharge of heat to the atmosphere or to fresh or marine waters, depending on the type of cooling system used; (2) occasional emission or flaring of excess components of gas.

110. The liquefied natural gas (LNG) is transported by LNG tankers. The capacity of these tankers has greatly increased in the last 15 years as a result of the increase in production and consumption of natural gas. (Table 16).

Table 16 - Capacity of World LNG Tankers*

	1960	1970	1975
Number of ships	1	14	36
Fleet capacity (1,000m^3	5	1500	5000

* After Rob (1975).

111. Liquified natural gas consists mainly of methane and there is a possibility of an explosive evaporation if the LNG comes in contact with water. There is also the tendency of stratification if two LNG's different in composition are mixed,for example, in storage tanks. In such cases, an increase of pressure inside the storage tank might occur and lead to an explosion if safety measures are not adequately taken.

112. If liquefied natural gas is spilled, it boils rapidly. Although the vapour is not toxic, it may in high concentration cause asphyxiation by excluding oxygen. Moreover, the low temperature of the material may result in frostbite for anyone in the immediate vicinity of a spill. Both of these potential hazards are too localized to be of concern outside the boundaries of the liquefaction facility. The major hazard of liquefied natural gas is, however, fire and adequate safety measures are normally taken to prevent such accidents.

113. Little is known about the biological effects of LNG when spilled in the sea. Methane, the principal constituent of natural gas, is relatively non-toxic to freshwater species. There is no reason to suspect that this gas would be more toxic to marine organisms. Toxicity of natural gas would probably be associated with such sulphur-containing impurities as hydrogen sulphide and mercaptans. However, these would be normally removed from the gas prior to liquefaction.

Environmental Impacts of Oil Processing (Refining)

114. Refineries are large industrial installations with air and water emissions, large water requirements for processing and cooling - unless air cooling is used extensively - and safety problems due to the risk of explosions and fires. A 300,000 bbl/day refinery require about 520 hectare of land for direct use and an additional 520 hectare as exclusion area. The latter is the area that surrounds the plant site where no resident population is allowed for safety-related reasons (OECD, 1978).

115. The principal types of refinery airborne emissions and their potential sources are given in Table 17.

Table 17 - Potential Sources of Emissions from Oil Refining*

Type of Emission	Potential Sources
Sulphur oxides	Boilers, catalyst regenerators, decoking operations, flares, heaters, inciderators, treaters, acid sludge disposal.
Particulate matter	Boilers, catalyst regenerators, coking operations, heaters, incinerators.
Hydrocarbons	Air blowing, barometric condensers, blowdown systems, boilers, catalyst regenerators, compressors, cooling towers, decoking operations, flares, heaters, incinerators, loading facilities, processing vessels, pumps, sampling operations, tanks, turnaround operations, vacuum jets, waste-effluent-handling equipment.
Nitrogen oxides	Boiler catalyst regenerators compressor engines, flares.

* After: Mallat (1977).

116. Small amounts of carbon monoxide are also emitted, the sources of which include: catalyst regenerators, coking operations, gas generators, flares boilers, and process heaters. Of these sources, catalyst regenerators from catalytic cracking units and fluid bed cokers generate continuously significant amounts of carbon monoxide. Because catalytic cracking units could be significant point sources of carbon monoxide, emission standards in many countries require catalytic cracking units, to reduce CO emission, usually by secondary combustion. Table 18 gives an estimate of airborne and liquid effluents from an oil refinery processing 2.5×10^7 crude oil (equivalent to 1000 MW(e)y).

Table 18 - Emissions from Oil Refinery (tonne) (per 1000 MW(e)y)*

Airborne Effluents	
SO_x	21,000
Organic compounds	23,000
NO_x	18,000
CO	4,300
Ammonia	2,230
Liquid Effluents (1.4×10^8 tonne waste water) containing:	
Chlorides	24,000
Grease	600
Ammonia nitrogen	600
Phosphate	3
Suspended solids	2,000
Dissolved solids	100,000
Trace metals (Cr, Pb, Zn, Cu)	22

* Calculated after Wilson and Jones (1974) and Korte (1977).

117. Refineries require large amounts of water, mainly for heat removal and in various process operations. Each process operation has different water usages associated with it, and the characteristics of the wastewaters produced differ considerably. In addition to cooling water and process wastewaters, ballast water, storm water runoff, and sanitary wastes also contribute to the total waste load that refineries must treat before discharge.

118. The most significant pollutants present in these various wastewaters are oil and grease, phenols, ammonia, suspended and dissolved solids, sulphides, and chromium. In addition, some wastewaters are highly alkaline while others are acidic. As a result of widely differing water usages and processes in refineries, the quantity and quality of wastewaters varies considerably from refinery to refinery. These wastes, however, are readily treatable with a combination of in-plant controls and treatment techniques and end-of-pipe treatment. The last consists mainly of primary separation of oil and solids and neutralization, followed by biological treatment using activated sludge systems, aerated lagoons, or oxidation ponds. The pollutants named above are largely removed; the effluents discharged from most refineries contain them in only low concentrations (Mertens and Allred, 1977).

119. While growing amounts of information on the biological effects of oil spills on the aquatic environment are becoming available, little has been written on the biological effects of refinery effluents. The toxicity of individual contaminants present in these effluents, however, is fairly well documented. The effects, if any, of the contaminants present in refinery effluents on the aquatic environment can be determined by bioassay techniques. Unfortunately, current bioassay procedures used to monitor the effects of refinery effluents on water quality and aquatic life are cumbersome and expensive in terms of the required time, facilities, technicians, and test organisms. Consequently, only a fraction of all refinery effluents can be monitored for toxicity (Mertens and Allred, 1977).

120. Odour can be a potential nuisance in and around a refinery. The principal malodorous compounds existing in crude oil or formed during its processing into products are hydrogen sulphide and mercaptans. Should any of these escape from a refinery there is a risk of smells in the neighbourhood. Ethyl mercaptan has a perceptible smell when present in a concentration of only one part per thousand million; thus even a very small loss can create an unpleasant smell downwind under certain meteorological conditions.

121. Accidental spills at refineries can occur from stored crude oil or refined products. In 1974, a huge oil tank in the Mizushima refinery on Seto Inland Sea, Japan, developed an 8 m rupture and lost about 50,000 barrels of oil to the sea. The spill affected the area considerably and extensive cleaning efforts were undertaken to restore the area. The total cost of the damage have been estimated at $160 million (Nicol, 1976; Hiyama, 1979).

Environmental Impacts of Oil and Natural Gas Utilization

Use of Oil Products:

122. A variety of oil products is used as energy sources; gasoline, gasoil, kerosene and residual oil are the most common. Mobile sources contribute currently more to the total emission of carbon monoxide and hydrocarbons than stationary sources (Table 19). It is estimated that in the U.S.A. the motor vehicle contributes almost 65% to all anthropogenic carbon monoxide and about 46% to all anthropogenic hydrocarbons emitted to the atmosphere. Vehicle exhaust emissions are, therefore, of major public concern. The complete combustion of gasoline under ideal conditions should result in exhaust gases composed of water vapour and carbon dioxide. However under actual driving conditions the exhaust gases also contain unburnt hydrocarbons and carbon monoxide. The amount of these latter substances may vary considerably not only in accordance with the driving conditions, but also among different cars and different engine designs.

Table 19 - Emission Sources in Urban Areas*

	Pollutant per cent of total		
	HC	CO	NO_x
Automobiles	50-60	77-87	40-50
Trucks, buses...etc.	5-10	8-10	8-13
Stationary sources	25-45	3-15	37-52

* After EPA (1974).

123. The fate and effect of lead additives of motor gasoline have been extensively discussed in recent years. Other additives used in motor gasoline are ethylene dibromide (or chloride) to reduce combustion chamber deposits and traces of other substances, e.g. boron compounds, to improve carburettor cleanliness, as dye or for similar purposes.

124. Regulations are now in force in some countries, to eliminate or reduce the use of antiknock additives and to reduce the emission of unburnt hydrocarbons, carbon monoxide and in some cases also oxides of nitrogen. It is assumed that by 1985 the emission of carbon monoxide and hydrocarbons will be reduced by about 75 per cent of the 1972 level. However, the reduction of the total emission into the atmosphere may be less since it is expected that from 1972 to 1985 the world car population will increase from 208 million units to 373 million units, i.e. almost double (UNEP Motor Vehicle Seminar, 1977). This would result in a reduction of only 50% of the total emission of these pollutants.

125. Spills of refined products might occur during transportation of the products from storage facilities to gas stations, etc. or during loading/unloading operations. However, safety precautions should present such spills and consequently health hazards and possible fires.

126. The use of residual oil in power stations gives rise to a number of effluents. These are summarized in Table 20. The environmental impacts of these effluents are discussed in Chapter V.

Table 20 - Effluents from Oil-fired Power Stations
(tonne/1000 MW(e)y)*

Airborne Effluents	
SO_x	37,000
NO_x	24,800
CO	710
Hydrocarbons	470
Aldehydes	240
Particulates	1,200
Liquid Effluents	
Suspended solids	497
H_2SO_4	83
Chlorides	26
Phosphates	42
Boron	331
Chromates	2
Organic compounds	66
Solid waste	
(collected fly ash)	9,190

* Calculated after Wilson and Jones (1974). The power plant uses $2x10^6$ tonne residual fuel (1% S, 0.5% ash); thermal efficiency 38%; Fly ash recovery 99%.

Use of Natural Gas:

127. Natural gas can be used for domestic, industrial or power production purposes. Table 21 gives an estimate of effluents from a power plant operated with natural gas.

Table 21 - Effluents from a Natural Gas-fired Power Plant
(tonne/1000 MW(e)y)*

Airborne Effluents	
SO_x	20.4
NO_x	$2x10^4$
Hydrocarbons	34
Other Organic Compounds	238
Particulates	510
Liquid Effluents	
Suspended solids	497
Organics	66
H_2SO_4	83
Chlorides	26
Phosphates	42
Boron	331
Chromates	2

* Calculated after Wilson and Jones (1974). The power plant uses $2.2x10^9$ m^3 of natural gas with energy value of 35,000 Btu/m^3, thermal efficiency 38%.

CHAPTER IV

OIL SHALE AND TAR SANDS

Oil Shale

128. Oil shale is a sedimentary rock containing hydrocarbons that can yield oil when retorted. The development of a commercial shale oil industry depends on the grade of the shale, the technology to produce the fuel, the ability to overcome institutional and environmental problems, and economic incentives that make investment worthwhile. Generally speaking, high grade oil shale contains more than 100 litres of oil per tonne of shale.

129. The recovery of oil from shale is accomplished by retorting, for which two generic methods have been developed: (a) on the surface in a retort vessel and (b) underground (in situ). Both surface and in situ retorting will produce a heavy oil that will be upgraded and converted into a transportable refinery feedstock. The ultimate products of refining can range from a low-grade boiler fuel to gasoline.

130. In the case of surface retorting of oil shale, mining is undertaken by underground or surface methods according to the geological occurrence of the shale. The amount of mined shale depends on the hydrocarbon content. On the average, about 50 million tonne of shale would be required annually for a plant producing 100,000 barrels of oil per day (Dickson et al., 1976). The mined shale is crushed to retortable size, heated in a retort to extract the oil and then disposed of the spent shale.

131. In situ retorting involves underground retorting with partial mining. To retort oil shale, the formation is fractured and ignited. The shale is heated to 400°C or higher to bring about pyrolysis of the kerogen (the organic portion of the oil shale) and production of shale oil and gas. Combustion is sustained by pumping compressed air, and the produced gases and liquids are forced or pumped horizontally through the fracture system to production wells which surround the site.

132. The development of a major shale oil industry will have a number of environmental impacts on the land, air, water, and natural resources of the region. The environmental disruption associated with oil shale mining is typical of that of any large surface or underground mining operation, except that size of the operation will mean that the scale of the disruption will be much greater.

133. In the case of surface retorting, the disposal of spent shale will create land disturbances of large magnitude, accumulation of toxic substances in vegetation, and contamination of ground and surface water from runoffs. Even under the best reclamation strategies, the naturally occurring ecosystems of the canyons in which the spent shale may be deposited will be completely covered and destroyed. The goal of reclamation is to establish a new ecosystem on the spent shale piles, which can be self-sustaining long after human involvement has ended. This goal involves stabilization of the pile against erosion and sliding, establishment of a suitable plant cover, and ultimately the generation of a plant succession system similar to other systems in the area. Some of the spent shale can be returned to the mine. This is most readily accomplished if surface mining is employed, since it can be done in conjunction with the return of overburden to the mined-out areas. A part of the spent shale can also be returned to the mine if underground mining is employed. In either case, disposal problems will remain since the volume of shale expands under retorting (10 to 30 per cent, depending on the retorting process used) and not all the spent shale can be returned to the mine. Furthermore, temporary disposal sites will still be required since several years of mine development are needed before backfill operations can begin. In general, the prospects for achieving a long-term stable ecosystem on massive spent shale piles have not been fully assessed and it remains one of the major problems of oil shale development.

134. The oil shale industry will exert a potential impact on local water resources due to the demand for clean process water, the need for removal of process effluent discharges and mine dewatering. Mining operations, especially underground mining in arid and semi-arid regions, will cause long term hydrological disturbances in the region. The mining of shale horizons that separate fresh water aquifers from saline aquifers in the Mahogany Zone, U.S.A., for example, will lead to contamination of the fresh water with saline water; the fresh water aquifer recharges the streams of the region (Rattien and Eaton, 1976). The demand for water by the oil shale industry has not been accurately assessed. Estimates range from 100 to 200 million m^3/year for a one million bbl/day operation. This large amount of water will have to be obtained in some cases by diversion of water courses locally available, which will cause environmental disruptions in the region.

135. During the retorting and upgrading of oil shale, waste water is generated. Such water contains phenols, hydrogen sulphide, ammonia and trace chemicals, and should be treated and re-cycled. A potential source of water pollution is leaching or runoff from the spent shale disposal pile into local aquifers. Except in catastrophic failure of the pile or flash flooding, catchment dams will probably be sufficient to retain any runoff water. The potential for water contamination due to leaching depends on several factors, such as the degree of compaction of the spent shale, and has yet to be fully assessed.

136. A number of air pollutants are encountered in oil shale processing. Table 22 summarizes the emissions produced from surface retorting and from in situ extraction of oil.

Table 22. Air pollutants from oil shale processing operations; 50,000 bbl of oil/day. (After Rattien and Eaton, 1976)

	Quantity (tonne/y)	
	Surface Retorting*	In situ Extraction
Particulates	320-3245	1576
Sulphur oxides	955-5835	8406
Nitrogen oxides	609-6412	2256
Carbon monoxide	291-3634	72
Hydrocarbons	1386-4041	971

* The range covers different technologies for surface retorting.

137. The question of the fate of toxic trace elements in oil shale conversion processes has received considerable attention due to the potential for highly toxic metals such as mercury, lead, beryllium, arsenic, cadmium, selenium and fluorine, to enter air, water, or soil and ultimately to create health hazards. However, the fate of these elements during oil shale retorting has not yet been clearly defined.

Tar Sands

138. The term "tar sands" has been defined as sand having a "highly viscous crude hydrocarbon material not recoverable in its natural state through a well by ordinary production methods". Tar sands are more appropriately referred to as bituminous sands or oil sands as "tar" is defined as a substance resulting from the destructive distillation of organic matter. Major tar sand deposits occur in Albania, Canada, Malagasy Republic, Romania, Trinidad, U.S.A., U.S.S.R. and Venezuela, (Phizackerley and Scott, 1967). Estimates of world reserves of tar sand bitumen vary widely from conservative estimates of 915.2 billion barrels to the high estimate of 2,100 billion barrels of oil in place (Demaison, 1976).

139. Table 23 gives some of the reserve estimates of tar sands. Most deposits in countries other than those listed in this table are poorly recorded and are considered to have in-place bitumen amounting to less than 1 million barrels.

Table 23. Estimates reserves of major tar sands deposits of the world

Country	Reserve Estimate (Million Barrels oil)
Venezuela	200,000 (a) - 1,050,000 (b)
Canada	710,800 (a) - 895,000 (c)
U.S.S.R.	144,000 (b)
U.S.A.	27,000 (b) - 30,000 (d)
Malagasy Republic	1,750 (a)
Albania	317 (a)
Trinidad	60 (a)
Romania	25 (a)

(a) Phizackerley and Scott (1967).
(b) Demaison (1976).
(c) Demaison, Ibid., Govier (1973), Walters (1974), Phizackerley and Scott, Ibid., Jardine (1974).
(d) Frazier (1976).

The enormous deposits of the Orinoco Heavy oil belt (Venezuela) and the Alberta Tar Sands (Canada) account for over 90% of the world reserves of tar sand bitumen. Deposits in the U.S.S.R. and the U.S.A. account for nearly 8% of world reserves.

140. The first commercial scale tar sand plant, went into operation in 1967 in Alberta, Canada, and has produced an annual average of 45,000 bbl/day since then. The second Canadian plant, began production of synthetic crude in 1978. By 1985, production is expected to reach 125,000 bbl/day. In 1972, the U.S.S.R. started operating a commercial "thermal mining" plant to produce high viscosity crude from the Yarega oil field, about 1,400 km northwest of Moscow. These operations are the only "commercial" size tar sand plants currently in operation. Small scale local exploitation of tar sand has been common in many localities throughout the world for many years, mainly for asphalt recovery or other non-fuel uses. At present, there are numerous pilot-scale operations being developed around the world to test and develop tar-sand production technology or to enhance heavy oil recovery.

141. Tar sand deposits can be mined either from surface or deeper deposits depending on the geological setting of the sand-bearing formations. Surface mining technologies are generally similar to those used for coal. The tar sand is mined and transported to a processing plant where the bitumen is extracted and the sand discharged. The extraction system is based on the hot water extraction process, cold water separation or anhydrous solvent separation process. Deeper deposits are generally uneconomic to mine by underground technologies, and the separation of bitumen from such deposits may be accomplished by in-situ extraction processes. These involve the application of heat, solvents, emulsification, bacterial action or thermal cracking. Two advantages of in-situ over surface mining methods are that the former would eliminate the need for handling and processing vast tonnages of bitumen-bearing materials and for disposing of the resultant spent sand tailings. One disadvantage, from a resource utilization point of view, is that recovery efficiency will probably be no greater than about 50 per cent compared to about 90 per cent bitumen extraction from mined tar sand.

142. The environmental effects of large-scale tar sands development could be widespread and severe, if insufficient planning and financing accompanies such development. Although many aspects of oil sand excavation are comparable to coal mining, the basic differences are the spent tailings sands and sludge material. Table 24 presents types of terrestrial environmental disturbance that could result from a surface tar mining operation. Of the types indicated, those that actually occur, as well as their duration and severity, will depend on details of mining and material handling methods employed; size of the operation; all elements of the premining environment; and the degree to which environmental protection measures are employed during planning, mining, and surface restoration phases of the operation. Generally, factors determining the degree to which the area of a tar sand mine can be restored to a pre-mined status should not differ from those of a surface coal mine in the same area with one significant exception; namely, reclamation and revegetation of tailings sand. The most abundant solid waste material produced by extraction is the mineral matter sent as tailings to the settling pond. For a tar sand facility producing 10,000 bbl/day of synthetic crude oil product, about 23,211 tonne/day of this mineral matter will be rejected in this manner. Depending upon the requirements of an operation e.g., government regulations, extraction process, and method of transportation of tailings sand, methods of disposing of tailings sand include: (1) Temporary disposal in pond areas until the sand can be disposed of permanently in mined out areas without interfering with mining operations; (2) Permanent disposal behind dams near a mine or processing plant. Revegetation of tailings sand has been the subject of considerable research. The total direct land disturbance of a major tar sand mining operation can be very significant. It has been estimated that more than 200 km^2 will be disturbed over a period of 25 years to supply a plant producing 120,000 bbl of oil per day (ECE, 1978).

Table 24. Environmental impacts of tar sands mining (After Frazier et al., 1976)

Operation or Source of Impact	Potential Impact								
	Increased Landslide Risk	Destruction of Existing Vegetation	Alteration of Habitats	Topographic Changes	Drainage Diversion	Increased Noise	Solid Waste Generated	Changes of Ground Water	
								Physical	Chemical
Site Preparation		X	X	X	X	X			
Surface Clearing (cleared area)		X	X	X	X	X	X		
Stripping		X	X	X			X	X	X
Tar Sand Extracting (mined area)				X		X		X	X
Haul Road Transporation (construction)		X	(X)	X	X	X			
Tailings Disposal						X	X		
Bitumen in Tailings or Low Grade Tar Sand Waste		X							X
Solubles or Water-borne Particles in Overburden			X					X	X
New Surface									X
Increases in Surface Slope From Waste Disposal	X								
Rehandling of Material: Backfilling, Grading and Recontouring						X			

143. In-situ production of tar sands offers much less potential for surface impacts than surface mining. Some vegetation would normally need to be cleared and the gound graded to accommodate equipment installations, but only relatively small areas would be affected. Surface operations can be conducted so as to avoid or minimize interference with concurrent land usages such as livestock grazing, or agricultural activities. Produced sand and drill cuttings would constitute the major solid wastes associated with in-situ production. The produced sand should sand should not be significant if gravel packing or other sand filtration methods are applied in the well bore. The sand that would be produced could be separated from the bitumen and probably discharged into a pit that would later be back-filled. The cuttings produced from the drilling operation could also be disposed off by procedures commonly employed in the oil production industry - burying in a pit and back-filling at the completion of the drilling operations. Disposal of drilling muds should pose little to no potential for environmental impacts because these muds are customarily collected and reused.

144. The mining operation of a tar sand plant produces water problems closely similar to those of a conventional coal mining operation. Ground water present in the tar sand must usually be removed by wells and discharged prior to mining operations and this water may be saline and/or toxic. Surface mining operations that disturb existing, or expose, new surfaces, increase availability of soluble and suspendable constituents for aqueous transport. Duration and severity of impacts on water quality resulting from these operations depend on terrain, climate, details of mining method and environmental protection practices, geochemistry of overburden, methods of transporting ore and/or tailings sand, surface drainage patterns, and the hydrogeology.

145. Excluding possible effects of chemical differences between tar sands and coal, the types of impacts on water quality of a surface tar sand mine would be essentially similar to those of a surface coal mine in the same area. The organic phases of tar sand bitumen are more similar to petroleum than to coal. Hence, exposed tar sand surfaces and unrecovered bitumen in spent processed sand, if exposed to the physical action of runoff, will be a potential non-point source of organic loading (primarily alkane - or paraffin-type hydrocarbons of heavy molecules with lesser amounts of aromatics) that is not associated with a surface coal mine operation.

146. Sulphur in tar sand bitumen is present as organic compounds which are oil solubla and are not generally leachable. Also, trace metals in the bitumen are present as oil soluble organic compounds, e.g. porphyrins and salts of organic acids. Although a majority of these compounds are insoluble in water, some could hydrolyze and the metallic ions become soluble in water. If the hot water process is used, some components of the bitumen, including metal compounds, aliphatic and aromatic organic

acids, would be expected to react with the extraction water and dissolve (hydrolyze). The effect of this is to make the tailings pond water toxic to aquatic life, and hence unsuitable for discharge into natural water bodies. Further, some bitumen remains in the tailings and a thin slick of bitumen and lighter hydrocarbons form on the surface of the tailings pond. This slick can pose a hazard to water-associated birds that alight on the pond through bitumen-fouling of feathers. The currently accepted solution to the problem of tailings water contamination is to design "zero-discharge" plants, with the tailings water being impounded and recycled through the extraction plant to the maximum extent possible. Loss of water from a tailings pond on a "zero-discharge" plant can come from evaporation, from inclusion in deposited sludge on the bottom of the pond, and from seepage through dykes or into natural ground water below the pond.

147. Air emissions from mining and extraction operations of tar sands are quite similar to those from surface mining of coal except that as tar sands are exposed, volatiles in the bitumen are an additional emission source. Materials handling operations can produce dust, particularly if overburden or rehandled waste is dry and unconsolidated. Haul roads are a source of dust when transporting ore and spent sand. Water or hygroscopic materials can be used to reduce dust generated from this source. A problem that has been identified in the Athabasca area is the production of "ice fogs" from the large tailings ponds. These "ice fogs" are generated in very cold environments (-30°C and below) when exposed water surfaces are available, or when water vapour is otherwise released. The problem of ice fogs is not unique to tar sands operations, but accompanies many very cold climate operations.

148. Gaseous by-products would constitute the major atmospheric discharge associated with in-situ combustion. The volumes of gases produced with the bitumen could vary considerably depending on the deposit conditions, the type of production mechanism, and the characteristics of the bitumen in place. The produced gas would usually contain varying amounts of sulphur compounds (SO_x, H_2S, ... etc.) nitrogen, carbon dioxide, carbon monoxide, oxygen and hydrocarbons. A review of 24 different wet and dry in-situ combustion recovery projects on heavy oil reservoirs showed the following average range of concentrations of the produced gases (Farouq, 1972):

Oxygen - 2.5-3.5%
Carbon dioxide - 10-17%
Carbon monoxide - 0-2%
Hydrogen sulphide - 0-2%
Methane - 0-2%
Nitrogen - the balance

149. The gaseous produced in conjunction with in-situ tar sand production will probably be very lean and lack sufficient heating value to justify collection and processing for marketing. They might be either vented from the water knockout and separation tanks to the atmosphere, or combusted further to completely oxidize the carbon monoxide, hydrogen sulphide, and methane. Other air emissions associated with in-situ recovery projects are the exhaust discharges from diesel or gasoline-powered equipment and dust generated from vehicles travelling the access roads.

150. Upgrading operations at a tar sand plant are the primary source of atmospheric emission with potentially detrimental effects on the environment. The emission that has provoked the most active debate in Canada is sulphur dioxide, but particulate materials, water vapour, hydrocarbons, vanadium and nickel and other substances potentially emitted from a bitumen upgrading plant are also of concern.

CHAPTER V

ENVIRONMENTAL IMPACTS OF POLLUTANTS FROM FOSSIL FUEL COMBUSTION

1. Sulphur Oxides

151. Sulphur is a relatively abundant element which plays an essential part in the environmental cycle. On land, it is found in rocks as sulphide and sulphate and in the oceans it is present predominantly as dissolved sulphate. In the atmosphere, however, the principal sulphur compounds are hydrogen sulphide, sulphur dioxide and sulphate aerosols and mists.

152. Sulphur compounds are not accumulating in the atmosphere. A cycle operates whereby sulphur is continuously transported between the different phases; and there is a balance between the release of sulphur into the atmosphere and its return to the Earth's surface, although over the last 100 years or so, the increasing amounts of atmospheric sulphur generated by man may have shifted the balance point. This is shown by recent changes in the sulphur content of polar ice, which had previously remained constant over the centuries (Koide and Goldberg, 1971).

153. Over the past several years estimates of natural and man-made (anthropogenic) sulphur emissions have been made for global sulphur budget calculations. Table 25 lists some of these estimates. On a global basis, fossil fuel combustion accounts for 75-85 per cent of man-made sulphur emissions, and industrial processes such as refining and smelting account for the remainder.

Table 25. Emissions of sulphur into the atmosphere (in 10^6 tonne S/y)

	Natural Emissions			Man-made
	Volcanoes	Sea-Spray	Biogenic	
Junge (1963)	-	45	230	40 (12.7)*
Eriksson (1963)	-	45	280	40 (11.0)
Robinson and Robbins (1972)	-	44	98	70 (33.0)
Kellogg et al. (1972)	1	44	89	50 (27.3)
Friend (1973)	2	44	106	65 (30.0)
Bolin and Charson (1976)	3	44	31	65 (45.5)
Hallberg (1976)	3	44	37	65 (43.6)
Granat (1976)	3	44	32	65 (45.1)
Garland (1977)	-	44	152	70 (26.3)
Davey (1978)	10	44	86	60 (30.0)
Cullis and Hirschler (1979)	5	44	97	94 (39.2)

* Figures between brackets are percentage of man-made emissions.

These estimates have large uncertainties, particularly in the case of natural emissions, where the magnitude of biological decay emissions is adjusted to make budgets balance. However, they show the magnitude of the contribution of man-made emissions. About 75-80 per cent of man-made sulphur is deposited on land (Granat et al., 1976). The Northern Hemisphere accounts for about 93 per cent of the global man-made SO_2 emissions and has approximately two-thirds of the Earth's land area. Thus most of the global man-made sulphur is deposited back onto the continental Northern Hemisphere, whereas a relatively small amount finds its way to land in the Southern Hemisphere (MARC, 1978).

154. Though they are not well understood, the mechanisms by which SO_2 is oxidized to sulphates are important because they determine the rate of formation and, to some extent the final form of sulphate. Atmospheric SO_2 may be oxidized to SO_3 and converted to sulphuric acid aerosol, or it may form sulphite ions that are then oxidized to sulphate. Subsequent to the oxidation, sulphuric acid or sulphate may interact with other materials to form other sulphate compounds. The most important sulphate formation mechanisms identified to date include: direct photo-oxidation, indirect photo-oxidation, air oxidation in liquid droplets, catalyzed oxidation in liquid droplets and catalyzed oxidation on particulates. The conversion of SO_2 to sulphate aerosol in power plant plumes is slow in the early part of the plume; that is, close to the point of emission. As ambient air mixes with the plume, the rate of conversion increases. Thus tall stacks reduce ground-level concentrations of SO_2 but increase sulphate aerosol formation by reducing sulphur losses of SO_2 and by increasing the atmospheric residence time, which results in increased SO_2-to-sulphate conversion (Wilson et al., 1977 in the atmosphere and a consequent spread of sulphates over a greater area.

Effects of sulphur oxides:

155. Although more quantitative data on dose-response relationships are needed, sufficient evidence exists to conclude that atmospheres polluted with oxides of sulphur directly and indirectly attack and damage a wide range of materials. Much of this damage is due to the conversion of sulphur oxides to highly reactive sulphuric acid, and/or sulphates.

156. Atmosphere containing sulphur compounds can corrode several materials (for example, overhead powerline hardware, steel structures, etc.). It attacks and damages a variety of building materials - limestone, marble, mortar - as well as statuary and similar works, causing their physical deterioration (Kucera, 1976).

157. Although low doses of sulphur dioxide may have beneficial effects on plants, because sulphur is one of the major plant nutrients, an increased uptake of SO_2 will cause more and more changes in the system, first reversible, later irreversible, until a breakdown of the system occurs (Vogl, 1965). Plant species and varieties vary in sensitivity to sulphur

dioxide as a result of the interaction of environmental and genetic factors that influence plant response. Temperature, humidity, light, other pollutants and the stage of plant growth all interact in affecting this sensitivity. Sulphur dioxide absorbed by plants may produce two types of visible leaf injury, acute and chronic. Acute injury, which is associated with high concentrations over relatively short intervals, usually results in drying of the injured tissues to a dark brown colour. Chronic injury, which results from lower concentrations over a number of days or weeks, leads to a gradual yellowing (i.e. chlorosis, in which the chlorophyll-making mechanism is impeded). Different varieties of plants vary in their susceptibility to sulphur dioxide injury (Glass, 1978).

158. The interaction between soils and air-borne oxides of sulphur has received relatively little attention. The two major effects of SO_2 pollution of the soil are a decrease of pH and an increase in sulphate (Halstead and Rennie, 1977). A change of these two variables may then affect the structural and microbial characteristics of the soil. In some systems where the soils are sulphur deficient or where structure is improved by the addition of sulphur, increased productivity may result. However, these circumstances are relatively rare. When the rate of addition or the amount added is excessive, changes in the composition, structure, and function may result. Any effect of SO_x on vegetation will indirectly affect the soil.

159. Sulphur compounds are removed from the atmosphere by two processes (Glass, 1978): (a) dry deposition including the absorption of SO_2 on exposed surfaces and the sedimentation and impaction of particulates and (b) wet deposition in which sulphur compounds are frequently deposited as acid precipitation. Dry deposition is a continuous process depending mainly on the concentration of sulphur oxides near the ground, the yearly amounts deposited per unit area generally decreasing with increasing distance from the source. Wet deposition is much more variable being dependent both on the rainfall pattern and on the burden of sulphur compounds within the mixing layer. It can be substantial in areas exposed to precipitation from air which has passed large emission sources. In cold climates air pollutants deposited during the winter usually accumulate in the snow pack. When this melts, much of the pollutant load is released in concentrated form with the first melt water. This may lead to sudden increases of acidity in the watercourses and also to some extent in the soil.

160. Fresh water bodies in many areas of eastern North America and northern Europe, that today lie in and adjacent to the areas where precipitation is most acid, are threathened by the continued deposition and further expansion of acid precipitation. Many of these bodies of fresh water are poorly buffered and vulnerable to acid inputs. These ecosystems appear destined to suffer greater acidification and loss of fish populations. Equally as serious as damage to fish are the less conspicuous effects of the acidification of fresh water, including changes occurring in communities of aquatic organisms such as microdecomposers, algae, aquatic macrophytes, zooplankton and zoobenthos.

161. The acidification of thousands of lakes and rivers in southern Norway and Sweden during the past two decades has been linked to acid from precipitation (Dochinger and Seliga, 1976); Braekke, 1976; Wright and Gjessing, 1976; Almer et al., 1974; Dickson, 1975). In turn, this increased acidity has resulted in the decline of various species of fish, particularly trout and salmon. The fish population in rivers and lakes in 20% of the area of southern Norway have been affected by increasing acidity. About 10,000 Swedish lakes are estimated to have been acidified to a pH below 6.0 and 5,000 lakes to a pH of less than 5.0 (Dickson, 1975). Along the west coast of Sweden, about 50% of the lakes have pH values of less than 6.0 and pH has decreased as much as 1.8 units since the 1930's. Fish populations have been correspondingly decimated or seriously affected (Dickson, 1975).

162. Other evidence indicates that not only are fish affected by acidification, but that a variety of other aquatic organisms in the food web are adversely altered (Dochinger and Seliga, 1976; Braekke, 1976; Hendrey et al., (1976). In general, algal communities in lakes with pH under 6.0 contain fewer species, with a shift toward more acid-tolerant forms. In particular, the chlorophyceae (green algae) are reduced in acid lakes. Some acid lakes and streams contain greater amounts of benthic moss (Sphagnum) and attached algae, and the growth of rooted plants is reduced. There is a tendency toward fewer species of aquatic invertebrates both in the water column and in sediments in acid lakes and streams. The rate of decomposition of organic matter is reduced, with bacteria becoming less dominant relative to fungi. Swedish workers have observed thick fungal felts over large areas of sediments in some acidified lakes. They concluded that decreased decomposition of organic matter on the bottom of lakes, coupled with greater abundance of submerged mosses and fungal mats, reduces nutrient cycling from the sediments. This in turn leads to depletion of nutrients and reduced productivity in acid lakes.

163. Acid precipitation also causes other changes in lake-water chemistry as well. Elevated concentrations of aluminium, manganese, zinc, cadmium, lead, copper, and nickel have frequently been observed in acidified lakes (Wright and Gjessing, 1976; Beamish, 1976; Dickson, 1975). The abnormally high concentrations are apparently due in part to direct deposition with precipitation as well as increased release (solubility) from the sediments in acidified lakes (Dickson, 1975; Galloway et al., 1976; Galloway and Likens, 1977). These heavy metals may represent a major physiological stress for some aquatic organisms.

164. In recent years concern has been expressed that forest growth may also be affected far away from emission sources, where the concentration of acid in air and precipitation is lower than where acute damage and visible symptoms occur. The rate of forest growth has declined in southern Scandinavia and in the northeastern U.S.A. between 1950 and 1970, but it is not possible to state unequivocally that this decline is caused by acid precipitation (Abrahamsen et al., 1976; Dochinger and Seliga, 1976; Tamm, 1976). Terrestrial ecosystems are very complex, with numerous

living and non-living components. Since acid precipitation is only one of many environmental stresses, its impact may enhance, be enhanced by, or be swamped by other factors. Recent experiments indicate that acid precipitation can damage foliage; accelerate cuticular erosion; alter responses to associated pathogens affect the germination of conifer seeds and the establishment of seedlings; affect the availability of nitrogen in the soil, decrease soil respiration; and increase leaching of nutrient ions from the soil (Abrahamsen et al., 1976; Malmer, 1976; Tamm, 1976). Although many of these factors might be expected to adversely affect tree growth, it has not yet been possible to demonstrate unambiguously decreased tree growth in the field. However, it is possible that acid damage might have been partly offset by the nutritional benefits gained from nitrogen compounds commonly occurring in acid precipitation. Changes already detected in soil processes may as yet be too small to affect plant growth.

165. Sulphate aerosols contribute to a large extent to the reduction in visibility. In regions prone to high relative humidities some phenomena may aggravate the sulphur dioxide - sulphate - visibility relationship (Glass, 1978). First, there is an increased conversion rate of sulphur dioxide to sulphate thus, more net sulphate may be formed due to the reduced opportunity for SO_2 removal by dry deposition. Second, the visibility reduction of a sulphate aerosol always increases as the relative humidity increases because the particles grow in size. Therefore, if sulphur dioxide emissions cannot be kept at the recommended ambient values, rural and urban sulphate levels can be expected to increase, with a further visibility reduction. This can have socio-economic and climatic implications. The first ranges from simple citizen dissatisfaction to decrease in revenue and property values in area of scenic attraction. Climatological effects include the reduction of solar radiation for photosynthesis, heating or cooling of the atmosphere resulting in changes in the length of growing seasons, and changing precipitation levels (Higgins, 1977).

166. One of the primary problems in determining the health effects of sulphur dioxide continues to be the development of an understanding of the manner in which this gas interacts with other substances in the atmosphere. Laboratory studies have demonstrated that the levels of sulphur dioxide found in the ambient air are innocuous until combined with other substances. Three categories of human disease appear to be influenced by atmospheres containing sulphur dioxide and associated pollutants. These are: altered pulmonary ventilation and increased prevalence of lower pulmonary disease in children, increased frequency or severity of asthmatic attacks; and increased prevalence of chronic respiratory disease. During so-called air pollution episodes an increased mortality has been observed in susceptible groups, e.g. persons with heart and lung diseases, and the aged. Moreover, high concentrations of sulphur dioxide and particulates have been associated with acute morbidity.

167. The results from investigations on exposed workers are to a certain extent contrary to the findings in epidemiological investigations of the general population. For example, in studies of workers exposed to sulphur dioxide, it is obvious that medical symptoms have been reported first when the exposure was considerably higher than during even acute air pollution episodes. However, the type of exposure has not been comparable with the exposure from ambient air. Furthermore, occupational groups consist of relatively young and healthy persons while the general population includes also the aged and the infirm. Among occupational groups there is a certain self-selection which means that those who object to the exposure change jobs. All of these factors make it impossible to use the negative results from investigations of exposed workers as a basis for making meaningful quantitative risk evaluation pertaining to the general population. It should also be pointed out that effects were observed at concentrations of about 3 mg/m^3 SO_2 in short-term experiments on human volunteers (WHO, 1979).

168. It is evident from animal experiments that high concentrations of sulphur dioxide can bring about pathological changes in the airways of a similar nature to those seen in patients with chronic bronchitis. At lower exposure levels, about 3 mg/m^3, changes in lung functions have been seen as well as a reduced lung clearance. Although animal experiments have provided evidence that synergistic action takes place between sulphur dioxide and particulates, the conclusion must nevertheless remain that the effects in animal experiments occur at a much higher level of SO_2 than in the case of human beings.

169. A World Health Organization Task Group made an evaluation of the lowest concentrations of sulphur dioxide and particles which could be expected to cause health effects. Acute effects can be expected after simultaneous exposure for 24 hours to 250-500 μg/m^3 of both sulphur dioxide and particles. Respiratory symptoms can also be expected as a result of long-term exposure to 100 μg/m^3 sulphur dioxide and particulates (WHO, 1979). Based on this evaluations, guidelines for the protection of the health of the public were developed in terms of 24-h values (100-150 μg/m^3) and in terms of annual means (40-60 mg/m^3).

170. This evaluation is based primarily upon results from epidemiological investigations. This leads to difficulties in quantitative generalizations. It cannot be excluded that substances other than sulphur dioxide and particulates may have been of crucial significance. For example, in those investigations on which the evaluations are founded the concentrations of nitrogen dioxide were not measured. Nor is there information available on the concentration of sulphur compounds other than sulphur dioxide, e.g. sulphate particulates. When it comes to apply the results to the present exposure conditions it should also be stressed that the particulates primarily consisted of soot which is not the case today. All of these factors mean that it is not possible, with any substantial degree of certainty, to establish values for sulphur dioxide and particulates (alone or in combination with each other) which can be expected to give rise, or, not to give rise, to health effects.

171. Morgan et al. (1978) estimated the health damage* due to sulphates to vary from 0 to 12 deaths per 10^5 people per microgram/m^3 sulphate with a median of 3.7. This value was applied by Morris et al. (1979) to estimate the health hazards from coal-fired power plants. Table 27 gives the amount of SO_x emitted from fossil fuel fired power plants with no stack gas desulphurization together with the calculated mortality due to sulphur oxides.

Table 27. SO_x emissions from fossil fuel fired power plants and the estimated health effects (per 1000 MW(e)y

	Coal	Oil	Natural Gas
Tonne SO_x emitted	$11x10^4$	$3.7x10^4$	20
Excess deaths	20	6	0.004

Assuming stack height of 300 m, $3x10^6$ people within 80 km around power plant. For other information regarding efficiency of power plants, sulphur content of fuel, see Chapter II and III.

Control Technology:

172. Several technologies have been developed forflue gas desulphurization, namely, limestone slurry scrubbing, lime slurry scrubbing, manganese slurry scrubbing - regeneration to H_2SO_4, sodium solution scrubbing - SO_2 reduction to sulphur, and catalytic oxidation (Cheremisinoff, 1976; Yan, 1976). The selection of technology is essentially controlled by its cost. Of these flue gas desulphurization systems, lime/limestone wet scrubbing is now considered a commercial process, land use restrictions may prevent the application of lime/limestone systems in regions of high population density. Assuming a coal with a sulphur content of 3% and a scrubber efficiency of 90%, the amount of waste water produced is about $6.1x10^6$ tonne (containing $7x10^5$ dissolved and suspended solids) per 1000 MW(e)y. Such water requires a settling pond about 7.2 hectare (3 m deep); the recovered solids require 10 hectare (6 m deep) storage facility. Such scrubbers reduce considerably the emissions of SO_x and hence the associated health effects.

2. Nitrogen Oxides and Photochemical Oxidants

173. Nitrogen oxides, primarily NO plus smaller quantities of NO_2, arise from a different source than other pollutants. Basically, nitrogen in the combustion air (plus, possibly, small quantities of nitrogen chemically contained in fossil fuels) combines with the oxygen in the air during the

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* See para. 16 and 17 for discussion of dose-effect relationship. The estimates given here are assuming linear relationship.

combustion process to produce NO. Later, most of the NO oxidizes further to form NO_2. Most NO_2 is formed outside the boiler, often at a considerable distance downwind from the plant stack.

174. The emission of nitrogen oxides varies greatly from one country to another (see Table 28). However, the major source of world-wide atmospheric NO_x is naturally produced, especially by biological processes. Man's contribution is nevertheless a cause for concern because the emissions are concentrated in urban areas (NO_x concentrations in urban atmospheres are 10 to 100 times higher than those in rural atmospheres).

Table 28. Emissions of Nitrogen Oxides as NO_2 (10^3 tonne/year) in some selected countries*

Source	Canada 1972	Fed. Rep Germany 1971	Italy 1972	The Netherlands 1970	Norway 1970	United Kingdom 1970
Area 10^3 km^2	9976	248	301	36	324	244
Transportation	1092	414	314	108	46	360
Stationary Combustion	445	1296	432	140	19	1602
Industrial Process	63	41	118	35	15	-
Miscellaneous	63	-	-	-	-	-
Grand Total	1663	1750	864	284	80	1962

* Emissions of nitrogen oxides are expressed as NO_2. Most sources are emitting much more NO than NO_2. Oxidation of NO into NO_2 is a function of time and the photochemical processes. Thus NO/NO_2 are dependent on the distance between source and measuring site, time of day, and meteorological parameters. The reason for expressing NO_x emissions as NO_2 is due to the fact that formally NO was measured together with NO_2 after oxidation into NO_2. Recently, however, NO concentrations may be measured as such. (To express the NO_2 emissions as NO multiply the values given in the table by a factor of about 0.6).

After OECD (1976).

Effects of Nitrogen oxides:

175. Nitrogen oxides can cause plant injury. Some kinds of plants develop acute leaf injury (lesions) when exposed to concentrations of NO_2 greater than 25 ppm for one hour. However, at normal ambient NO_x concentrations, there appears to be no appreciable harm.

176. Nitrogen dioxide is well known as a toxic gas in industrial environments. It can, if inhales in high enough concentrations, produce pulmonary aedema which occurs only after a latent period. The concentrations found in polluted air are rarely more than 0.1 to 0.2 ppm and could not produce pulmonary oedema, but there is evidence from animal experiments that the concentrations not much higher than those occasionally found in outside air can produce cellular alterations and structural changes resembling those seen in some human lung disease. On the other hand, very little work has been done on the toxic effects of NO mainly because it used to be thought that it was oxidized immediately to NO_2. However, NO is a very active molecule, capable of forming addition compounds with haemoglobin as does carbon monoxide and more work is needed to study its true effects (OECD, 1978).

177. A limited number of epidemiological studies have been published in which an increased incidence of acute respiratory tract infections in school children have been associated with the exposure to nitrogen oxides. A simulataneous exposure to other air pollutants took place, however, and it is not possible to identify a straight forward relationship between exposure to nitrogen dioxide alone and respiratory diseases.

178. An evaluation of health effects of nitrogen dioxide must, therefore, rely on experimental data as relevant epidemiological studies are not available. There is indication, however, that adverse effects occur after short-term exposure to about 1-2 mg/m^3 NO_2 (0.5-1 ppm). These effects include not only morphological changes and other toxicological effects observed at higher NO_2 levels, but also certain effects seen at lower levels. These include increased airway resistance, increased sensitivity to broncho-constrictors and enhanced susceptibility to respiratory infections. In healthy humans adverse effects have been seen after ten minutes of exposure to about 1.3-3.8 mg/m^3 (0.7-2 ppm). Some data suggest that exposure to about 0.2-0.4 mg/m^3 may give rise to adverse effects in asthmatics under conditions of a simultaneous exposure to bronchoconstrictors (WHO, 1977). At present, there is no evidence that nitric oxide concentrations typically observed in the ambient air have a significant biological effect (WHO, 1977).

179. In 1972, WHO believed there was insufficient information upon which to base air quality guidelines in the absence of conclusive epidemiological data. The 1976 Task Group felt it was appropriate and prudent not to wait further but to employ toxicological and experimental data from animals and humans to derive guidelines for the protection of public health. The Task Group selected 0.5 ppm NO_2 as an estimate of the lowest observed effect level for short term exposures. In view of the uncertainty concerning the lowest adverse effects level and the high biological activity for NO_2 the Task Group concluded that a considerable safety factor was required.

Accepting a safety factor of 3-5, the minimum exposure levels consistent with the protection of public health would become 0.10-0.17 ppm maximum, one hour concentration not to be exceeded more than once per month (WHO, 1977). However, some experts also feel that these exposure levels might have to be lowered if there is biological evidence showing interaction between nitrogen dioxide and other pollutants present if some segments of the population appear to be highly sensitive to NO_2. Because of the lack of information on the effects of long-term exposure to nitrogen dioxide, only a short-term exposure has been proposed. A number of countries have established ambient air quality standards for NO_2. They cover a wide range from 0.01 to 0.1 ppm for 24 hour averages and from 0.02 to 0.45 ppm for 20 minutes to one hour averages (OECD, 1978).

Photochemical Oxidants:

180. Nitrogen oxide emissions are of particular concern because they are "starting" materials for atmospheric reactions which lead to the production of photochemical oxidants (photochemical smog). Oxidants are formed when nitric oxide reacts with hydrocarbon vapors in the presence of sunlight. Major components formed are ozone, nitrogen dioxide, peroxyacyl nitrate and peroxybenzoyl nitrate.

181. It has been established that photochemical oxidants are only a local problem in the large urban areas because of either topography or population distribution. However, recent evidence from field studies conducted in Europe and Eastern North America has established that photochemical pollutants and their precursors can be transported up to several hundred kilometres. This long range transport implies that emission control on a local scale may be grossly insufficient in Europe and Eastern North America (OECD, 1978).

182. Different effects on man and his environment, attributed to photochemical air pollution, have been noted in many parts of the world. The variations in the type of effect are due to a number of factors such as the variety of pollutants present, their respective concentrations, their cyclical occurrence, their interaction, etc. Few systematic research programmes on health effects, plant damage or other types of effects have been carried out during episodes of photochemical air pollution.

183. While a large number of compounds fall into the group known as photochemical oxidants, the one which is formed most abundantly in the ambient air, and about which is most known in ozone. It is difficult to obtain an accurate measurement of all the photochemical oxidant compounds in the air, therefore most air monitoring stations only measure ozone which generally composes over 90 per cent of the total photochemical

oxidant in the air. Most of the health studies, however, have been based on exposure to ozone rather than to a combination of oxidants as would occur in the air. In fact, little is known about the toxicity of many specific photochemical oxidant compounds other than ozone and PAN (peroxyacetyl nitrate), but some are strongly suspected of being dangerous to humans, mainly aldehydes (formaldehyde, acrolein), other peroxyacyl nitrates, sulphate and nitrate aerosol species.

184. The primary toxicological effects of oxidants are increased susceptibility to infectious pulmonary disease; pulmonary and systematic biochemical changes; eye, nose and throat irritation, nausea and headaches; impairment of pulmonary function; structural changes in lung tissue; and chromosomal alterations of white blood cells. From laboratory experiments on humans and animals, it appears that some of the effects definitely can be attributed to ozone, others such as eye irritation, cannot be caused by ozone, because ozone does not possess any lachrymatory properties (Hazucka, 1973; Bates and Hazucha, 1973; Hazucha and Bates, 1975; Watanabe et al., 1973; Sato and Frank, 1974).

185. Carefully controlled laboratory experiments in the United States (EPA, 1976) have shown that ozone interferes with the normal function of the lung in healthy adults at levels above 0.25 parts per million, when ozone is the only air pollutant present. Some of the health effects can, however, be expected to occur at ozone levels considerably below that observed in this laboratory test. This is because ozone is known to have synergistic properties, i.e., the health effects are much more pronounced when ozone and other common air pollutants e.g. SO_2, NO_2, are breathed simultaneously than when breathed alone.

186. To obtain more information and to help answer questions which cannot be answered through human experiments, scientists have tested a variety of animals under controlled conditions for long periods of time. These studies showed that, at levels and durations of exposure comparable to those experienced in many areas of the United States, serious health effects occur in animals. These include chromosome changes, permanent damage to the elastic recoil properties of lungs, decreased fertility, birth defects, and, possibly, lung cancer. A further disturbing observation from animal studies is that at very low concentrations (0.08 ppm) for several hours, ozone reduces the body's capability to fight off infectious bacteria (OECD, 1978, WHO, 1978).

187. Consideration has to be given to the limitations of interpreting laboratory animal and human studies. However, these studies have proved both necessary and useful in understanding the health effects of ozone. There is a need for more systematic epidemiological studies to be undertaken so that more definite conclusions on the long-term effects of relatively low concentrations of oxidants can be reached. More controlled animal and human studies with ozone and combinations of pollutants would also prove valuable.

188. Photochemical oxidants can affect plants in a number of ways, e.g., necrosis, bronzing, silvering, etc. of leaves, and in reducing yield and output. This latter effect is of particular importance for commercial crops. Damage to commercial crops has been reported in a number of countries, mainly Canada, the Netherlands and the United States. As a result of this damage occurring over several years, farmers in certain areas such as Ontario have switched to less sensitive species or to other crops. The commercial crops affected by ozone include white beans, tomatoes, tobacco, lettuce and spinach (OECD, 1978).

189. An increasing number of countries are using indicator plants to monitor for oxidants as this method is cheap and very useful in situations that do not justify the establishment of a complex and costly monitoring network. In this respect, Canada has reported on several studies concerning indicator plants that show leaf injury to sensitive species of tobacco plants to be consistent with ozone concentrations obtained by instrumental methods (OECD, 1978).

190. In north-western Europe, north-eastern United States, Los Angeles, Tokyo and Sydney, visibility reduction is an important effect of photochemical pollution episodes. Photochemical reactions lead to the oxidation of sulphur dioxide and nitrogen dioxide to aerosol species which cause the dense summer hazes regularly observed over hundreds of kilometres. Since one of the main removal mechanisms of these aerosol particles is by precipitation, these species may travel quite long distances during photochemical episodes. The aerosol in the polluted photochemical air mass has been observed to reduce the intensity of the solar beam to one tenth of the incident value.

191. In 1972, the WHO published a tentative air quality criteria value for urban areas of 0.06 ppm ozone. In 1976, WHO convened a Task Group to produce an updated air quality criteria document. The no-effects value for ozone was found to be 0.1 to 0.2 ppm. The Task Group reached a consensus that a one hour mean ozone concentration of 0.05 to 0.1 ppm not to be exceeded more than once per month, should be a guideline for the protection of public health (WHO, 1978).

Control Technology:

192. Theoretically, it is possible to reduce NO_x concentrations in combustion gases by: (1) modifying the burners or firebox, or both; (2) decomposing nitric oxide and possibly nitrogen dioxide, back to the elements oxygen and nitrogen; or (3) scrubbing the effluent gases. Of the three possibilities, modifications of the combustion equipment have been shown to be the most effective and probably offer the most promise of further NO_x reduction at combustion sources. For stationary sources, the

control principle has been based on reducing either the flame temperature or the availability of oxygen, both of which prevent NO formation. Similar principles of control are applicable to motor vehicles. Catalytic principles, which have been applied to reduce NO_x from chemical processes, may also be applicable to the control of NO_x in motor vehicle exhaust.

3. Carbon Monoxide

193. Carbon monoxide (CO) is a product of incomplete combustion of carbonaceous fuels and is formed whenever carbon-bearing materials burn, if the oxygen furnished is less than that required to form carbon dioxide. By far, the largest source of CO emission is motor vehicles. Industrial sources normally are remote from urban areas, and their emissions make no significant contribution to the high CO levels experienced in inner-city areas. Even in the immediate vicinity of major industrial sources, CO levels are generally well below the allowable ambient air quality standard. The carbon monoxide background concentration of clean air has been found to be 0.13-0.14 ppm in the northern hemisphere and 0.06 ppm in the southern hemisphere. The worldwide emissions of CO have been estimated to be more than 200 million tonne annually.

194. Several removal processes of CO are known. The oxidation of CO by OH radicals seems to be the most important sink. Additionally, carbon monoxide is removed by such natural processes as the metabolic conversion of CO to CO_2 and methane by soil micro-organisms.

195. Table 29 gives the carbon monoxide emissions from different sources in the United States, and illustrates that transportation devices account for about 75 per cent of the carbon monoxide emitted. Distinct seasonal patterns of variations in carbon monoxide emissions are known, these are primarily the result of both traffic and meteorological variables.

Table 29. Carbon Monoxide Emission Estimates by source category for the United States*

Source	CO X 10^9 kg/year	Percentage
Transportation	101.0	73.7
Fuel combustion in stationary sources	1.6	1.2
Industrial processes	10.8	7.9
Miscellaneous	23.7	17.2

* Source: UNEP/GC.61/Add. 1.

196. There is no evidence that the carbon monoxide discharged as a result of man's activities is of any global significance. The only adverse effects known occur in urban areas (especially road tunnels and confined spaces with heavy traffic) where levels can rise sufficiently to block a small proportion of the oxygen-carrying capacity of the blood.

197. When inhaled, carbon monoxide combines with haemoglobin, whose vital function is to transport oxygen. Since carbon monoxide has an affinity for haemoglobin some 240 times that of oxygen, the prime result of this reversible combination is to decrease the capacity of the blood to transport oxygen from the lung to the tissues. It should be noted that carbon monoxide is naturally present in the blood, the normal background concentration of blood carboxyhaemoglobin (COHB) is about 0.5 per cent, and this is attributed to endogenous sources such as catabolic processes. Exposure to carbon monoxide in the air does not necessarily raise the level in the blood. For example, continuous exposure to 25 ppm of carbon monoxide will eventually result in 4 per cent saturation, irrespective of the initial concentration in the blood (a person with an initial saturation of less than 4 per cent will absorb the gas, while a smoker with an initial saturation greater than 4 per cent will exhale carbon monoxide until the COHB concentration falls to 4 per cent). The saturation level of 4 per cent has been selected since higher levels appear to increase the risk for patients with cardiovascular disease.

4. Particulates

198. Suspended particulate matter can result from natural and man-made sources. The former include volcanic activity, dust storms, forest fires, sea salt spray ... etc., while the latter include mainly emissions from combustion and industrial processes. Robinson and Robbins (1968) estimated the annual global emission of particulate matter from natural and man-made sources to be of the order of 2600×10^6 tonnes, of which man-made sources constitute 296×10^6 tonnes (or about 11.4 per cent). The burning of fuel (especially coal) for heating and for the generation of power has been one of the major contributors to the suspended particulate matter in urban air. Vehicular traffic also generates particulate compounds from the exhausts of petrol-engined vehicles, and black smoke from those of diesel vehicles.

199. The significance of fine particulates for plants and animals derives from certain aspects of their physical presence and their chemical composition. Constituents with potential toxicity for plants include B, Cd, Co, Cr, Cu, F, Ni, Tl, and V. Constituents important for animals include Be, Cd, F, Hg, Ni, Sb, Se and Tl. The five trace elements with greatest potential for adverse impaction the terrestrial biota, ranked in descending order of biological impact and research need include Cd, Ni, Tl,

Cu, and F (Van Hook and Schults, 1977). Of particular interest is the evidence suggested that some trace elements are preferentially concentrated on the smallest particles (Linton et al., 1976). Some elements also are present in the gas phase (Natusch, 1975; Natusch and Wallace, 1974; Andren et al., 1975; Pellizzari et al., 1975; Jones et al., 1976). While enrichment of particles appears to be independent of plant operating conditions, stack gas temperature strongly influences the distribution of elements between phases.

200. Recently, much more concern is being expressed about the potential toxicity of polycyclic aromatic hydrocarbons (PAH) which are released in coal combustion and can be condensed on the fine particulates. Studies in Norway (Lunde et al., 1976) have shown significant quantities of these compounds on particulates collected from regional air samples over southern Norway. Since the PAH compounds are known to be active in metabolism (including enzyme induction) and generate a wide range of metabolites, research is beginning to focus on their importance as carcinogenic agents for all animals breathing fine particulates, and for aquatic organisms taking up these compounds from the surrounding water (Lech and Melancom et al., 1977). Current research indicates important effects induced in fish at dilutions of a few parts per billion, well below levels observed in the Norwegian rainwater samples, but the hazard for human use of the fish is still unknown. Since most particulates in the future will be in the fine aerosol size, this may or may not represent a reduction in ecological hazard, depending on activity of these organic compounds.

201. Evidence also is available to indicate that the soil component of terrestrial ecosystems is an important sink for fine particulates. Studies of the ecology of soil ecosystems are concerned with the potential interference that the above trace elements can have on the metabolism of microorganisms, arthropods and other soil animals. Many of these organisms are involved in organic matter decomposition or mineralization. Subtle changes in these processes could have profound effects on ecosystem function by altering the quality or quantity of nutrient cycling (Bond et al., 1976; Lighthart and Bond, 1976).

202. Acute plant disease is infrequently ascribed to particulate contamination. Particulates, therefore, are generally not considered harmful to vegetation (Jacobson and Hill, 1970; U.S.D.A. Forest Service, 1973). In numerous and varied situations, however, particulates have been implicated in subtle adverse vegetation effects (Lerman and Darley, 1975).

203. Still another consequence of fine particulates is the reduction in photosynthesis occasional by reduced light from atmospheric contamination (Czaja, 1966; Darley, 1966; Treshow, 1970). Kellogg (1977) pointed out that particulates lead also to cooling of atmospheric temperature, but it is difficult to estimate the net climatic changes due to particulates from combustion of fossil fuels.

204. Different technologies are now available for the removal of particulates from flue gases (wet collection devices, electrostatic separators, ... etc.), and it is estimated that wider use and further improvement of these technologies may reduce particulates to about one-third of their present level by the year 2000. Unfortunately, however, the present removal devices remove particles down to one micron in diameter only. Finer particles remain suspended and are apted to be carried far from the source and even into the upper layers of the atmosphere. These fine particles contribute relatively little to the total weight of particulate emissions. There is growing evidence that these fine particles, which can lodge in the deep recesses of the lung, are the ones most responsible for adverse health effects. Small particles can interact with sulphur dioxide in the air to create a much worse health hazard than can SO_2 or particulate pollution independently. There is also growing evidence that small particles tend to worsen the impact of other pollutants on the environment. For short-term exposures, no satisfactory, direct evidence relating concentrations of total suspended particulates to effects is available (WHO, 1979). Because of this, a guideline for short-term exposure levels can only be inferred. A very approximate 24-h guideline for suspended particulate matter in the order of 150-230 ug/m^3 has been recently proposed by WHO (WHO, 1979).

5. Organic Compounds

205. A wide variety of organic matter is formed during the combustion process as a result of incomplete combustion or the occurrence of other chemical reactions. The quantities produced by the combustion of natural gas in conventional steam boilers are considered negligible. However, the quantities produced by the combustion of coal and oil are of possible significance, but can be minimized by good combustion control.

6. Trace Elements

206. Trace elements potentially hazardous to human health and ecosystems are present in fossil fuels, especially in coal. The trace elements of concern are, among others, arsenic, cadmium, chromium, mercury, lead, manganese, vanadium, fluorine and beryllium. Concentrations of these elements vary considerably among different types of fossil fuels. Extraction and combustion of fossil fuels effectively introduces these trace elements into the biosphere.

207. The calculated emissions of trace metals from coal and oil-fired power plants are given in Table 30. It should be noted that these values will differ from one plant to another, depending specially on the composition of the fuel.

Table 30. Emissions of Trace Elements (per 1000 MW(e)y) in tonne/y*

	Coal-fired Plant	Oil-Fired Plant
Arsenic	0.04	0.08
Cadmium	0.01	0.02
Chromium	16.00	0.07
Lead	0.90	1.00
Manganese	3.50	0.13
Mercury	0.58	0.003
Nickel	0.36	20.00
Vanadium	0.44	70.00

* Calculated after Freiberg (1977). For fuel and power plant characteristics see Chapter II and III. No desulphurization of flue gas.

Particulates, especially those in the submicrometer range are important "carriers" of these trace elements.

208. Little is known about the fate of metals emitted from tall stacks. Both modelling experiments and systematic grid sampling around power plants have indicated that less than 10% of the metals emissions can be accounted for within 50 kilometers of the plant.(Vaughn, 1975).

209. The trace metals components of the particulate portion of the SO_x-particulate complex strongly influence the response of experimental animals to the aerosol mixture. Some of the trace metals are known as promoting agents of the conversion of sulphur dioxide to sulphuric acid. Trace metal synergism with other air pollutants may well be the mechanism of greatest concern to public health, especially considering the long-range transport undergone by gases and small particulates emitted from tall stacks.

210. It is difficult to make an evaluation of possible health effects of the exposure to metals which will result from coal or oil fired power plants. The implications of a lifetime low exposure to such metals are not known. The possibilities of synergistic and catalytic effects upon other air pollutants have to be taken into consideration. Even if as a rule the concentrations of metals in the ambient air are small, the metals will not be broken down in nature. Several metals will undergo a continuous accumulation. In the evaluation of risks, it is therefore necessary to consider possibilities of contamination of air, water and crops, etc. from not only a local plant but also from other remote sources.

211. At nearly every point along the pathways in aquatic and terrestrial environments, interactions of trace elements with the biosphere occur. Organisms, especially micro-organisms in aquatic environments, can absorb, concentrate and transform trace elements into more concentrated forms or more toxic compounds. Biotransformation of trace elements is particularly important in determining effects on man and other organisms because the molecular form of these contaminants often determines their persistence, bioaccumulation and toxicity. Trace elements may enter food chains and undergo bioaccumulation in passing through higher forms of life. Of particulat concern in this regard are concentrations of mercury, cadmium and lead because current intake levels for these substances are near tolerable human health limits.

212. There is a reasonable agreement that some trace contaminants in coal may constitute health problems from either direct toxicity or risk of cancer. Among those most toxic to man are mercury, cadmium and lead; intake levels of these substances are normally near tolerable health limits. Some trace elements act as catalysts in the conversion of sulphur dioxide to acid sulphates and, in this way, may indirectly contribute to the respiratory irritant effects of these other combustion products. Other trace elements in fossil fuels can combine with sulphate ions to form biologically reactive and harmful compounds in the atmosphere. Three elements - arsenic, chromium and nickel - are accepted as having high carcinogenic risk to man. All three can appear adsorbed on fly ash, but their environmental impacts are not well defined.

213. Lead emissions are of particular importance since organic lead compounds (such as tetraethyl lead to tetramethyl lead) are generally used as additives to gasoline and are emitted to about 90 per cent as inorganic lead compounds. Alkyl lead has been observed in the urban air, in rush hours in concentrations about 1 microgram/m^3. Certain occupational groups, may be exposed to higher concentrations. About 30-40% of inhaled inorganic lead is absorbed. Absorbed lead is accumulated chiefly in the skeleton where over 90% of the total body burden is found. Lead is present in bone in an inert form. The remainder of the body burden of lead is distributed within the brain, liver, kidney and bone marrow. The concentrations in these organs are in general below 1 microgram/g. The metabolism of lead is complex. In blood and soft tissues, it probably has a relatively short biological half-time, 15-20 days (Rabinowitz et al., 1974; Chamberlain et al., 1975) while in the bone it has a half-life of over 10 years. The deleterious effect of inorganic lead compounds on different organs is well documented. Lead can cause anemia by interfering with the synthesis of haemoglobin in several ways. Lead can damage both the central and the peripheral nervous systems. A slowing on the conduction velocity of the peripheral nerves can emerge at concentrations around 50 microgram lead/100 ml blood (Seppäläinen et al., 1975).

7. Radionuclides

214. Studies have been made in the past few years of the amounts of naturally occurring radioactive substances emitted in the airborne effluents of coal-fired power plants (Eisenbud and Petrow, 1964, Terrill et al., 1976, Hyll, 1971; Lava and Freeburg, 1973 and McBride et al., 1978). The estimated annual airborne radioactive material released from a coal-fired plant is given in Table 31.

Table 31. Estimated Annual Airborne Radioactive Materials Released from a Coal-fired Power plant per 1000 MW(e)y*

Isotope	Releases, Ci/year	Isotope	Releases, Ci/year
U-238	$8x10^{-3}$	Th-232	$5x10^{-3}$
Th-234	$8x10^{-3}$	Ra-228	$5x10^{-3}$
Pa-234m	$8x10^{-3}$	Ac-228	$5x10^{-3}$
U-234	$8x10^{-3}$	Th-228	$5x10^{-3}$
Th-230	$8x10^{-3}$	Ra-224	$5x10^{-3}$
Ra-226	$8x10^{-3}$	Pb-212	$5x10^{-3}$
Po-218	$8x10^{-3}$	Bi-212	$5x10^{-3}$
Pb-214	$8x10^{-3}$	Tl-208	$1.8x10^{-3}$
Bi-214	$8x10^{-3}$		
Po-214	$8x10^{-3}$		
Pb-210	$8x10^{-3}$		
Bi-210	$8x10^{-3}$	Rn-220	0.4
Po-210	$8x10^{-3}$	Rn-222	0.8
U-235	$3.5x10^{-4}$		
Th-231	$3.5x10^{-4}$		
Pa-231	$3.5x10^{-4}$		
Ac-227	$3.5x10^{-4}$		
Th-227	$3.5x10^{-4}$		
Ra-223	$3.5x10^{-4}$		
Rn-219	$3.5x10^{-4}$		
Pb-211	$3.5x10^{-4}$		
Bi-211	$3.5x10^{-4}$		
Tl-207	$3.5x10^{-4}$		

* Assumptions: (1) the coal contains 1 ppm uranium and 2 ppm thorium; (2) ash release in 1%; (3) Rn-220 is produced from Th-232 in the combustion gases at the rate of $1.38x10^{-9}$ Ci $sec^{-1}g^{-1}$ of thorium; (4) the annual release of natural uranium is $2.32x10^4$g and Th-232 is $4.64x10^4$g; and (5) 15 sec is required for the gases to travel from the combustion chamber to the top of the stack. After McBride et al. (1978).

215. It should be noted that on the average, a member of the world population receives a whole body dose of about 100 mrem/y from natural radiation (cosmic rays, radioactive substances in the ground, etc.) and about 50-80 mrem/y from man-made sources (medical sources, nuclear explosions, power production ... etc.), of which less than 1.0 mrem/y is due to radiation from coal and nuclear power industry. The global dose commitment from one year of coal-power production at the present global installed capacity of 1000 GW(e) corresponds to 0.02 days of natural radiation exposure. One year production of nuclear power at present global installed capacity of 111 GW(e) gives 0.83 days of natural radiation exposure (UNSCEAR, 1977 p. 16).

8. Carbon Dioxide

216. Carbon dioxide is the final oxidation product of carbonaceous fuels; it is also an abundant compound, intimately involved in the natural cycle and essential to the maintenance of life. It exists in the ambient air at a concentration of around 300 ppm, and it is only if man's activities increase this value so as to interfere adversely with natural processes that carbon dioxide can be considered a pollutant.

217. Carbon dioxide is involved in continuous cycles of interchange between atmosphere and oceans, soil and rock layers, and the biosphere. Both land and marine plants withdraw and use carbon dioxide to create carbohydrate compounds. Animals consume plants, releasing carbon dioxide back to the atmosphere in the process of biological oxidation (respiration). Although the geochemical equilibrium keeps the atmosphere content of carbon dioxide fixed at a level of around 300 ppm, it has been reported that there has been an increase in atmospheric carbon dioxide concentration (Williams, 1978).

218. It is generally agreed that the carbon dioxide concentration has increased from about 300 ppmv in 1900 to about 330 ppmv in 1975 (UNEP, 1979). One reason for this increase must be the burning of fossil fuels, which has increased at a rate of slightly more than 4% per year during most of this century, and which presently adds about 5×10^{15}g carbon per year to the atmosphere. A second possible source of the increasing CO_2 is deforestation and destruction of soil organic matter, particularly in the tropics. There is much uncertainty in the magnitude of this source, but it is believed to be around $1-5\times10^{15}$g carbon per year at present (Hampicke, 1979; Bolin, 1979). Not all of the CO_2 added to the atmosphere by man's activities in any one year remains there and it is estimated that about 50% is taken up by other sinks. The major sink is the ocean but there has recently been considerable debate about whether the rate of CO_2 transfer into this sink is large enough to account for the difference between the additions of anthropogenic CO_2 to the atmosphere and the observed yearly increase in atmospheric CO_2 concentration. Other sinks have also been proposed, including reforestation or growth of the biota in temperate latitudes, peat accumulation and dissolved organic matter in the ocean. Despite uncertainty about the sources and sinks of CO_2, it seems clear that continued use of fossil fuels

(especially coal) will lead to a continued increase in the atmospheric CO_2 concentration, at least during the next 30 to 50 years during which the biogeochemical conditions, which have controlled CO_2 transfers during the last few decades, are not expected to change.

219. The reason for concern about the increasing atmospheric CO_2 concentration is because of the so-called greenhouse effect of the gas, which means, all other factors being constant, that an increase in the atmospheric CO_2 level would lead to an increase in the earth's surface temperature. Results from climate models suggest that a doubling of the CO_2 concentration would give an increase in the globally average earth surface temperature of 1.5-3°C (Schneider, 1975; Bach, 1978). However, the important question is: what will the regional changes of temperature and rainfall be? Studies with climate models and of climate observations (UNEP, 1979) indicate that the regional anomalies would occur, but the sign, magnitude and location of these anomalies cannot be reliably predicted at present. Thus it is not possible to make a detailed assessment of the impact on agriculture, water resources and human society, but if a doubling of the atmospheric CO_2 concentration were to occur within the next hundred years, then the change in globally averaged surface temperature would be greater than natural changes which have occurred during the last few thousand years, and this must be expected to have an impact on natural ecosystems as well as human activities.

220. In view of the concern about the CO_2 problem, several measures have been suggested to limit the amount of CO_2 going into the atmosphere, to remove CO_2 from the atmosphere or from the stacks of power plants, or to generate a climate cooling to compensate for the CO_2- induced warming (Marchetti, 1979). However, most of these measures are very costly or require a scale of operation presently not undertaken with technologies.

221. With regard to the input of CO_2 from fossil fuels into the atmosphere, a continuation of the present increase of 4% per year in the CO_2 input will probably lead to significant increases in the atmospheric CO_2 concentration within the next 50 years. Energy conservation is an important factor in energy strategies that would lead to significant reductions in energy demand, a process which would be of great importance in controlling the CO_2 problem. In contrast, recent responses to the "energy crisis" in the form of expansion in coal utilization on the development of some synthetic fuels will add to the problem.

222. The major uncertainties with regard to CO_2 at the present time concern the role of the terrestrial biota in the carbon cycle and the regional climatic impacts of an increase in the atmospheric CO_2 concentration. Until these uncertainties are resolved, it is not possible to say that the combustion of fossil fuels should be limited or halted but it is likewise irresponsible to say at the present time that the use of fossil fuels should be increased. Accelerated research efforts should, therefore be directed to

eliminating these uncertainties; in particular, a detailed assessment is required of the present rates of deforestation and soil destruction and associated fluxes of CO_2 into the atmosphere, further information is also needed regarding historic trends in these processes and regarding other changes in the terrestrial biota, which could also influence the atmospheric CO_2 concentration.

CHAPTER VI

OTHER ENVIRONMENTAL IMPACTS OF POWER PRODUCTION FROM FOSSIL FUELS

223. Like any other power station, the interaction between fossil fuel fired power plants and their surroundings has received considerable attention. The impact that a power station may have on the environment depends to a large extent on its location with respect to the load centre, populated areas, open water, agricultural land ... etc.

224. The siting of thermal electric generation power plants has recently become more complex. As the sizes of generators, boilers, and associated equipment have grown the problems of site location have increased. The present-day concepts of large fossil fuel fired plants will be met with greater problems of air and water quality control, as the number of plants to be constructed increases. There are several parameters that govern the suitability of the site of a power plant: the geological conditions of the site, the meteorological parameters, the availability of areas for fuel storage and disposal of wastes, terminals for the transportation of fuels to the plant, switchyard areas and location, access to transmission lines ... etc. The near-by availability of a source of cooling water is one of the most important pre-requisites in the selection of a site. The fossil fuel fired power plants, land requirements may vary from plant to plant depending on the situation of the plant with regard to open water, population areas and meteorological conditions. The average size requirement for a 1000 MW(e) plant varies from 80-120 ha. Additional land is needed for the switchyard and transmission lines. For coal-fired plants some additional 10 ha may be needed for coal storage at plant.

Thermal Discharges:

225. The heat produced by burning fossil fuels is extracted through suitable coolants which in turn runs a turbine to operate the generator to produce electricity. At the exhaust of the turbine the steam is condensed to water to maximize the energy conversion and then is returned to the boiler to repeat the cycle. A large amount of heat is rejected in the condensing process, and the rejected heat is greater than the heat equivalent of the electric energy generated. The thermal efficiency of modern fossil fuel fired power plants is approximately 38-40% which means that about 60% of the heat energy generated has to be rejected to the environment, in the vicinity of the power station.

226. The bulk of the waste heat is transferred from the steam to the cooling water in the condensers. Water is commonly used as the absorbent because of its general abundance, low cost, high specific heat, and ability to dissipate heat in the evaporation process. The cooling water is extracted from some suitable source (river or lake ... etc.), passed through the condenser where its temperature is increased by about 7°C, and returned to the source body of water. Eventually the warmed sink gives up this extra heat to the atmosphere. Such a system, which is referred to as "once-through" cooling, may cause unacceptable environmental changes. In such cases, it is necessary to eliminate thermal discharges to the water source by passing the heated cooling water through a separate "cooling pond" or "cooling tower" system and then returned it to the condenser for re-use.

227. A cooling pond is a large, shallow body of water that achieves its cooling by natural evaporation. Warm water from the condenser is pumped into one end of the pond and cooler water is extracted from the other end. A source of make-up water is required to replace the water lost by evaporation (usually about 3-5% of the water throughput). Cooling ponds are relatively inexpensive but require a rather large land area. A 1000 MW(e) plant may require about 400-1000 ha. Sometimes the water is mechanically sprayed into the air to enhance the evaporative cooling, in which case it is called a "spray pond".

228. Cooling towers can be classified as wet or dry. Wet cooling towers achieve cooling by evaporation, and so, like cooling ponds, require a source of make-up water. Dry cooling towers are closed systems and achieve cooling by conduction and convection. In such cases there is no loss of water. For economic reasons, dry cooling towers are very seldom used for power plants. For wet cooling towers, an outside source of make-up is required to compensate for the water lost by evaporation (about 3%), as well as water lost during "blowdown". Blowdown is the continuous or periodic flushing of the cooling system to remove solids and chemicals which accumulate in the circulating cooling water. This flushing can become a water pollution problem unless special treatment is provided. These towers also create huge plumes of water vapour which can contribute to local fogging and icing problems.

229. A water body provides the environment for many species of organisms, and changes in its temperature, chemical composition and flow rate may affect the number and kind of such organisms. Thermal discharges affect the water-based ecosystem to various degrees (Hutchinson, 1976; Hochachka and Somero, 1973, Coutant, 1975, Biswas, 1974, Gibbons, 1976). Heat influences all biological activity, ranging from feeding habits and reproduction rates of fish via metabolism to changes in nutrient levels, photosynthesis, eutrophication and degradation rate of organic material. It is also necessary to distinguish between thermal effects in temperate and tropical or sub-tropical habitats. In temperate habitats, as water temperature starts to decrease at the end of the summer, the ecosystem activity is reduced as well. Addition of heated water from power plants

may then maintain the level of ecosystem development. In contrast, in the tropics and sub-tropics, the water temperature would be high in summer, and additional thermal input could be detrimental. This could be especially important for water bodies that become shallow in the summer, and under such circumstances, the siting of power plant becomes an important consideration. In any case, it should be noted that whereas many studies are available on the effects of thermal discharges in temperate climates, information is more limited on tropical and sub-tropical climates, where the effects could be more pronounced. Seasonal changes could be critical to certain species at specific stages of their life cycle (Hutchinson, 1976). Although studies have been conducted on a variety of organisms, predictions as to the effects of temperature changes and maximum temperatures still cannot be made with certainty especially if the changes are gradual, occur for only a short time, or affect limited areas or volumes of large bodies of water.

230. When properly controlled thermal discharges have resulted in an increase in the ability of certain commercially valuable aquatic species to multiply, while at the same time decreasing the time for the species to reach maturity. Experience has shown that at a number of plant locations the discharge of waste heat to a stream or reservoir has improved fishing in the vicinity of the discharge during the cooler months of the year. This increase in fish populations in heated discharge regions due to higher availability of nutrients has led to the apparent paradox that most fish kills have occurred not during the release of heated effluents but whenever a plant shutdown occurs suddenly due to load dumping or equipment failure. This phenomenon, known as "cold shock", results from the sudden cooling of the water plume to whose temperature the fish have become acclimatised, leaving them with a suddenly reduced body temperature, in a state of stupor, and suffering a loss of equilibrium (Coutant, 1977). Unless the temperature is raised again quickly, the fish may die in a matter of minutes or a few hours. The effect is most pronounced during the cold season when ambient water temperatures are low. It can be minimized either by lowering the temperature slowly to give the fish a chance to adjust to the new temperature or to seek other pastures, by diffusing the heated water well, or by combining the discharge mixing zones of several plants so that the shutting down of any one plant has a less drastic effect on the temperature of the receiving water.

231. Another major cause of fish kills in the entrainment of small fish in the intake water at velocities too high for them to escape, leading to death either by impingement on the trash screens or by thermal shock as they are carried through the condenser pipes. Thus, the use of water for cooling purposes at steam-electric plants may have effects on aquatic organisms other than those resulting from purely thermal discharges. The destructive effects of passing fish and their larvae or eggs through pumps and condensers may indicate the need for intake screens, preferably with travelling screens having little or no impingement velocity. The most visible environmental impact of some power plants has been due to fish kills resulting from improperly designed intake structures, leading to

impingement and mutilation of passing fish on the trash screens. Most recent designs incorporate wide-intake, low-velocity systems with trash racks whose main function is to remove driftwood and other solids, with finer screens to remove algae and other entrained plants and animals.

232. Before entering the condenser system the water has to be purified, softened and demineralized, so that the water leaving the plant will be cleaner than the inlet stream. In addition, chemicals used intermittently for defouling the condensers could adversely affect fish and fish food organisms. Thermal discharges enhance the solubility of chemicals and the rate of biochemical reactors, and this may be significant in view of the wide range of plant chemicals, such as detergents, algicides, corrosion inhibitors, that may be contained in the plant effluents (IAEA, 1975).

233. Much has been written and experience acquired about the possible beneficial uses of thermal discharges (Belter, 1975; IAEA, 1975, 1977; Biswas and Cook, 1974; Lee and Sengupta, 1977) from power plants. Of all beneficial uses, the most promising appears to be the employment of waste heat for residential and industrial space heating in the winter and absorption-type air conditioning in the summer. Such waste heat utilization for district heating has been demonstrated successfully in several countries, for example in Sweden (Josefsson and Thunell, 1967), West Germany, Finland, France and the U.S.A. Agriculture is also a potential user of waste heat. Irrigation with heated water could promote winter seed germination and growth and extend the growing season. Hot houses are used to grow tropical or sub-tropical crops in more temperate regions. However, a number of problems need to be solved before large-scale use of heated water for irrigation could become common practice. Also, the effects of any plant shut-down on such uses of warm water has to be explored. An obvious advantage of raising the temperature of the receiving body of water is in the provision of ice-free shipping lanes and ports. However, the range of waterway affected may be limited to 16-30 km of ice-free water, and the adverse effects on the ecology would be most pronounced during the summer months. Another potential use of condenser discharge water is in aquaculture. Marine and freshwater organisms may be cultured and grown in channels and ponds fed with heated water. For example, it may be possible to grow commercially valuable oysters in the area where they cannot normally reproduce or survive due to low water temperatures. Culture experiments with shrimp, eel, white fish and other species have been carried out with thermal discharges in some countries, and it has been reported that growth rates measured for shrimp and snapper are much higher in the 7°-8°C warmer discharge water than at natural temperatures (Belter, 1975). In the U.S.A., catfish production operations are being carried out in conjunction with steam-electric power plant operations in Tennessee and Texas. Aquaculture is also practiced in France and other countries.

Transmission Lines:

234. The environmental impact of high-voltage transmission lines* may be considered with regard to six aspects: aesthetic considerations, land requirements, communications, hazards, ozone, and habitat effects. Since underground lines at this time are limited to 250 kV and to short-range distribution systems, high-voltage transmission lines will remain part of our environmental scene for a considerable time. Efforts have been made to design more attractive towers and to select cables permitting longer free distances between towers. Routing can take advantage of topographical features to reduce visibility, and use of higher transmission voltages will reduce the number of lines radiating from major power centres. Land requirements will vary with the number of lines and the height of towers, but the right-of-way for major transmission lines may be 30-120 m wide. In general, use of the land below the lines is restricted to pasturing or low-intensity farming, though in most cases the utility may be sole owner of the right-of-way, may keep it fenced and restricted. In any case, it is evident that the land demand for easements associated with any new power station that may be 60 kms or more for major load centres will greatly exceed the land area of the plant itself and of the exclusion area. Regarding communication problems, high tension lines may cause some interference with nearby radio and television reception and may introduce fluctuation on signal strengths on windy days or under icy conditions. Tall towers and multiple lines may pose a hazard to air traffic, particularly under conditions of poor visibility, and air traffic terminals need to be suitably located.

235. Ozone may be generated by any corona or electrical discharge in air or other oxygen medium. The quantities produced depend on the severity of the discharge and the quantity of oxygen in the affected volume. Corona discharges can increase as a result of abrasions, corrosion effects, foreign particles or sharp points on electrical conductors, or incorrect design that produces excessively high potential gradients. Experimental work has been conducted to determine the added ozone production around a 1000 kV high-voltage test line. The results showed an insignificant increase in ozone concentrations over that produced by sunlight. Consequently, current types of high tension lines are not expected to produce harmful ozone concentrations.

236. Power line right-of-way has great potential as a wildlife habitat. Shear clearing through heavily forested areas is not inconsistent with good forestry and wildlife management practices. A common management

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* High-voltage transmission lines are common to all electric power stations: nuclear, fossil-fueled or hydro-electric.

practice in large sections of unbroken forest land is to open the tract by means of small, evenly spaced clearings. The rationale for this practice is to provide diversity and food in the forest environment. Wildfires originally provided this type of habitat. Power line right-of-way creates long linear forest openings that are indefinitely maintained to prevent power outages. The sunlight penetrating the forest via the right-of-way stimulates understorey growth adjacent to the power line. Periodic line maintenance may perpetuate these beneficial wildlife habitat conditions.

237. Transmission lines can have adverse impacts when crossing wetland areas. There is some evidence to indicate that behavioural modifications may occur for waterfowls, which could result in the absence of birds covering an area within 1 km of the transmission lines. The swaying of the lines in the wind, their reflective properties, and the humming of the lines could explain the abnormal behaviour of the birds. Direct current transmission could also have effects on migratory birds using magnetic homing. Electric fields associated with a transmission line can produce a charge on animals or human beings, within the range of its influence (Janes, 1977). Questions have been raised on the resultant effects of this displacement of currents on biological systems, but this is normally well below the values generally accepted as "safe" levels. Comprehensive reviews of existing studies on biological effects of high voltage electric fields are available (Kaufman and Michaelson, 1974; Bridges, 1975, 1977). Kaufman and Michaelson (1974) conclude that "research to date has failed to provide convincing evidence that human exposure to stationary or low-frequency electric fields has any harmful biological effect". According to Bridges (1975), "although the great bulk of evidence suggest that there are no significant effects of electric fields encountered under extra-high voltage lines, further research is needed".

Aesthetic and Recreational Factors:

238. Power plants vary widely in the visual impression they make on the viewer. Depending on one's point of view their appearance may be judged as blending harmoniously with their surroundings or as an insult to an otherwise attractive countryside. Objectively, suitable architectural treatment utilizing colours and textures, reflections in cooling ponds and a distribution of masses can do much to enhance the plants' appearance. There has been some objection to the appearance of tall hyperbolic cooling towers. To the observer who does not cherish their stark graceful lines they may appear objectionably obtrusive. Attempts to camouflage them by painting them or surrounding them with a shroud rarely have been successful; where their appearance is considered unacceptable, alternative means of providing comparable cooling capacity may have to be explored. The aesthetic impact of high voltage transmission lines has also been criticized. At the voltages in common use, 230 kV and 500 kV, underground lines are not feasible now. The plant location and power line routing should not therefore impinge on areas valued for their historic or touristic significance.

CHAPTER VII

SUMMARY

239. The rising global demand for energy has been met to an increasing extent by the use of fossil fuels, especially oil, which were cheap and plentiful. Recently, many countries have realized that non-renewable sources of energy are finite in extent and that diversification of energy sources is a must for future development. Concern for future energy supplies is refelected in the programmes of many national governments and in the efforts being made by a number of international organizations to assess global energy resources and possible rates of supply and substitution. Energy policies are nowadays influenced by several factors: population growth, level and nature of socio-economic activity,the relative costs of energy, the adequacy and reliability of supply, the availability of technology and supporting infrastructure, the success of energy conservation programmes and concern about the environmental and safety aspects of production and use of energy.

240. At local, national and in some cases regional levels, the environmental aspects of energy production and use have become the subject of wide-ranging debate. Environmental awareness and anti-pollution campaigns have affected the formulation of energy policies in many countries, and it has recently been realized that nations are not isolated in this respect: the actions of one country may affect the environment in a neighbouring one. Environmental objectives should not, however, be seen as being inconsistent with, or as imposing constraints upon, energy policy. A balance should be maintained between the need to preserve and improve the quality of the environment and the socio-economic goals and needs which depend on the availability of energy. Nowadays, energy policy decisions are dictated less by technological than by social, environmental and political factors. Although some countries are sensitive to the environmental aspects of energy production and use, there is still need for a comprehensive and more coherent consideration of the subject.

241. Fossil fuels (coal, oil and natural gas) are used for many purposes: domestic, industrial, transportation and for electricity production. The production, transportation, processing and use of fossil fuels have several environmental impacts; some are substantial and others small, some important and others of little consequence, some of short duration and others with long term effects and they might occur in different geographic areas and might affect different communities in different ways. For many environmental changes which are identified as impacts, the state of knowledge and technology will often only permit a qualitative assessment. Only in a few cases is it

possible to evaluate an impact quantitatively. Since fossil fuels account for about 75 per cent of the world electricity generation, the environmental impacts of the coal, oil and natural gas fuel cycles have been quantified in this report - when feasible - on the basis of 1000 MW(e)y for easy comparison between the different cycles.

242. Coal mining has a number of environmental impacts. The occupational hazards, especially the incidence of black-lung disease (coal worker's pneumoconiosis) are more marked in underground than in surface mining. The estimated fatal and non-fatal accidents in coal mining are about 0.6 and 45 per 1000 MW(e)y in underground mining; the figures for surface mining are 0.3 and 16, respectively. In underground coal mines the number of occupational deaths per 1000 MW(e)y is of the order of 0.21. It should be noted that these estimations would vary from country to another depending on the safety measures adopted to reduce such occupational hazards.

243. Coal mining, especially surface strip mining, has a potential impact on land. The land area disturbed vary according to the geological occurrence of the coal-bearing formation and its characteristic. Where surface mining is carried out in densely populated areas, it has a direct effect on human settlements and the total infrastructure in the area. Reclamation of strip mined areas has been successfully achieved in several countries. Both underground and surface coal mining have an impact on the water resources in the area of mining. Acid mine drainage has altered the water quality of more than 10,000 km of streams in the U.S.A. and has reduced or eliminated aquatic life in many of them. Different methods for treating acid mine drainage are known and stringent control measures are implemented in some countries to avoid the hazard of acid mine drainage.

244. Coal conversion processes are dually oriented: (a) to convert plentiful coal of different grades into scarce liquid and gaseous fuel and (b) to remove or treat, during processing, environmentally unacceptable or health - endangering compounds. However, coal conversion involves the handling of large amounts of coal often at high temperatures and pressures; it requires containment and control of both highly corrosive process materials and those that pose a possible health threat; and it calls for treatment and disposal of a voluminous solid waste and a possibly hazardous liquid and gaseous waste. Knowledge of these wastes and emissions and their environmental impacts is still incomplete.

245. Exploration and production of oil and natural gas, whether carried out on land or offshore, have a number of environmental impacts. Besides occupational hazards, offshore operations are of concern because of the possibility accidental oil spills. Although some field studies have shown that there is no ecological damage due to offshore operations, further studies are necessary to determine the long-term effects of hydrocarbons, accidentally spilled or resulting from normal

operations, on the marine ecosystem. This is particularly important for sensitive eco-zones such as tidal marshes, coastal wetlands, river swamps and sheltered bays.

246. Marine oil transportation is the most important means of transporting oil from oil-exporting to oil-importing countries. Although the world tanker fleet generally has a good safety record, the fact that ships today are so much larger than they were 20 years ago means that the consequences of an accident are potentially much greater. Experience has shown that such incidents can have serious effect upon the environment and marine life, damaging such important resources as fisheries and tourism for low periods. Although oil spillage from transportation (including normal and terminal operations) account for about 35% of all oil discharges in the sea, the consequences of a major spill near coastal zones are far reaching. The environmental impacts of such spill depend on the composition of the cargo (whether crude oil or refined products) and on the climatic conditions. The cleaning-up operations depend on a number of factors: ecological and commercial interests in the site of the spill, legal interests, technical factors and the cost of the cleaning-up operations.

247. Oil refineries are large industrial installations with air and water emissions, large water requirements for processing and cooling - unless air cooling is used extensively - and safety problems due to the risk of explosions and fires. The most important emissions from refineries are airborne effluents (SO_x, organic compounds, NO_x, CO and particulate matter) and liquid effluents. The latter contain a variety of compounds, the most important of which are oil and grease, phenols, ammonia and suspended and dissolved solids. These wastes are normally treated and the effluents discharged from most refineries contain low concentrations of such pollutants.

248. The exploitation of oil shale raises a number of economic and environmental problems. The environmental disruption associated with oil shale mining is typical of that of any large surface or underground mining operations, except that size of the operation will mean that the scale of the disruption will be much greater. In the case of surface retorting (recovery of oil from shale in a retort vessel) the disposal of spent shale will create land disturbances of large magnitude, accumulation of toxic substances in vegetation, and contamination of ground and surface water from runoffs. The oil shale industry will exert a poential impact on local water resources due to the demand for clean process water, the need for removal of process effluent discharges and mine dewatering.

249. The environmental effects of large scale tar sands development can be widespread and severe, if insufficient planning and financing accompanies such development. Land disturbance during the mining

of tar sands can be appreciable. The mine area can be restored as in the case of a surface coal mine, with one exception, the reclamation and revegetation. The most abundant solid waste material in the process of extraction of oil from tar sands is the mineral matter sent as tailings to the settling pond.

250. The combustion of fossil fuels(coal, oil, and natural gas) give rise to a number of airborne effluents, the most important of which are sulphur oxides, nitrogen oxides, carbon monoxide, particulates, organic compounds, trace metals and radionuclides and carbon dioxide. The quantities of these emissions vary according to the fuel used, its composition and the measures adopted at the power plant to reduce the emissions.

251. Man-made sulphur emissions account for about 40 per cent of the global sulphur budget of the atmosphere; 75-85 per cent of these man-made emissions are from fossil fuel combustion. Sulphur is normally emitted from power plants as SO_2 which is rapidly oxidized to SO_3 and converted to sulphuric acid aerosol or to sulphates. These oxidation products affect a wide variety of materials: plants, soil and other components of the biosphere. Sulphur emissions contribute largely to acid precipitation which has led to the acidification of several fresh water bodies in some countries, with consequent detrimental effects on aquatic life.

252. One of the primary problems in determining the health effects of sulphur dioxide and other emissions continues to be the development of an understanding of the manner in which these pollutants interact with one another in the atmosphere. Knowledge is insufficient to relate each airborne pollutant independently to health. The effects of airborne pollutants have been quantified in studies on animals, plants, in studies on man and in populations occupationally exposed to high levels of mixtures of different pollutants. Exact estimates of the hazards cannot be precisely difined without knowing the interactions creating the damage. Most epidemiological studies show good correlation between particulates and health effects; the correlation between SO_2 and health effects is less sharp, and it has been difficult to show correlation between impaired health and nitrogen oxides or oxidants. Particulates, especially fine ones that cannot be removed by present removal devices, one of particular concern because they can lodge easily deep in the lungs. Trace elements, polycyclic aromatic hydrocarbons, and other compounds adsorbed on these particulates increase the damage through synergistic effects.

253. Concern has been recently voiced at the implications of extensive coal utilization, especially its possible impact on climate. The atmosphere is believed to show a warming primarily due to the greenhouse effect of increasing carbon dioxide emissions. Studies with climate models and of climate observations indicate that regional anomalies will probably occur, but that the magnitude and impacts of these anomalies cannot be reliably predicted at present. The medium and long-term effects of such possible climatic changes are of such fundamental importance that they command serious attention.

254. The thermal efficiency of modern fossil fuel power plants varies from 38-40%, i.e. about 60% of the heat energy generated has to be rejected to the environment, in the vicinity of the power station. These thermal discharges can have detrimental effects on the water-based ecosystems and/or cause micro-climatic changes. However, thermal discharges have been put into beneficial use in a number of countries and further development prospects are under investigation.

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ANNEX I

I. Background Papers and Information

Background papers were prepared by:

1.	L. Freiberg	(Health effects of air pollution and trace elements)
2.	B.E. St. John	(Tar sands)
3.	T. Tarnawa-Tomaszkiewicz	(Coal)
4.	M. Waldichuk	(Marine transportation of fossil fuel)
5.	J. Williams	(Fossil fuels and climate)

Additional information were provided by IMCO, ECE, OECD, IAEA and IPIECA. Background papers for the UNEP seminars on Petroleum Industry and Motor Vehicle were also taken into account in addition to information gathered from literature. First and final drafts were prepared by Essam El-Hinnawi, Chairman, Energy Task Force, UNEP on the basis of this background material.

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