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"ECONOMIC ASPECTS OF THE RECYCLING OR DISPOSAL OF LOW-VALUE ORGANIC WASTES."

Submitted for the Degree of Doctor of Philosophy

January 1975.

THE UNIVERSITY OF ASTON IN BIRMINGHAM

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SUMMARY OF THESIS.

submitted for the degree of Ph.D.

"ECONOMIC ASPECTS OF THE RECYCLING AND DISPOSAL OF LOW VALUE ORGANIC WASTES".

(1)Object of Thesis.

The objects of this thesis are:

(a) to determine the economic conditions under which low - or marginal-value organic wastes may be (i) recycled, (ii) re-used for another purpose or (iii) disposed of;

(b) to determine the viability of processes for recycling this category of waste in general, and the viability of certain microbiological processes developed at the Biodeterioration Information Centre of this University in particular;

(c) to investigate the market and institutional factors governing the recycling and re-use of this waste and the obstacles to such recycling or re-use;

(d) to discuss in some detail the problems associated with three important types of waste in this category, viz. municipal waste, sewage effluent and agricultural wastes, partly to illuminate the points mentioned above;

(e) to attempt to relate the recycling of wastes to biological material cycles (a minor point).

(2)Argument.

The contention of this work is that (a) these low-value organic wastes create, on the one hand, various problems of disposal and are liable to give rise to various unpleasant spillovers if disposed-of unhygienically and constitute, on the other hand, a potential source for raw materials whose primary sources are under pressure or dwindling and which are becoming increasingly scarce; and (b) techniques can be and have been devised either to re-use this material or to dispose of it hygienically; the latter term

meaning that refuse and other waste is disposed of at the minimum cost to the environment in general and to human society in particular.

Which set of techniques is used for any particular waste will depend on the expected comparative net costs or benefits during the lifetime of the necessary investments;but it will be shown that because of increasing pressure on primary resources and increasing rent payable to the controllers of the same,re-use as against disposal is becoming increasingly competitive.

It will also be shown that there are still many technical (e.g.mixture of wastes,dilution,high bulk) and economic problems (e.g. institutional problems,relating output to expected size of market,inelasticity of supply) to be overcome before a satisfactory position is reached.

(3)Method.

This work is designed to argue from the general to the particular.It begins with a general introduction putting the topic and the thesis in its historical setting and which also attempts to define "wastes," discusses recycling patterns,relates the activity of the economy to that of the biosphere and introduces a distinction between recycling and ~~resource~~ re-use - important for wastes which often cannot be recycled into the primary resource stream.Energy problems are referred to,for completeness.(Chap.1)

Macro-economic issues are then discussed,especially the increasing rent in the price of diminishing resources.This is followed by a discussion of various micro factors on the level of the firm or authority contemplating recycling - including the introduction of the principle of the non-mixture of wastes.
The principles enunciated in previous chapters are then discussed with reference to the particular problems of household wastes, sewage effluent and farm wastes in that order;which chapters also attempt to explore the prospects of recycling those particular wastes

and attempt to evaluate certain projects developed at the Biodeterioration Information Centre (Chapters 4,5 and 6), viz. the biodegradation of used newsprint by thermophilic fungi as investigated by Dr.T.G.Barnes (Ph.D,1973) and the biodegradation of the solid fraction of farm animal wastes as investigated by Dr.K. Seal (Ph.D,1974).The final chapters summarise and conclude the argument and also discuss the limitations of economics when dealing with this type of problem.

Mathematical expositions have been avoided,except where their use clarifies the argument.

<u>(4) Conclusions.</u>

<u>(a)</u> Increasing costs of primary resources mean that there is a good economic case for the re-use of biosphere wastes in general.

<u>(b)</u> There is a spectrum of useability of these wastes - ranging from those already partly used (e.g. paper) to the unuseable (e.g. silage liquor).However,even in the case of those wastes that are already partly re-used,new institutions as well as new technologies are needed to exploit these materials.

<u>(c)</u> These wastes can only be reclaimed if they are not allowed to become mixed indiscriminately.The purposeful combination of two or more materials,however,is permissible.

<u>(d)</u> These wastes have limited potential value as an energy source.They have far more value as a materials source.

<u>(e)</u> While it is possible to conclude favourably on the prospects for re-using municipal waste and to a certain extent farm wastes,it was not possible to give a final verdict on the viability of the Biodeterioration Centre processes mentioned above,.

ECONOMIC ASPECTS OF THE RECYCLING OR DISPOSAL OF LOW-VALUE ORGANIC WASTES.

PREFACE.

I wish to acknowledge the help given to me by various persons and bodies during the course of this work. At the top of the list come, of course, Mr. A. J. Bennett, Lecturer in Economics at the University of Aston Management Centre (main tutor); Dr. H. O. W. Eggins, Head of the University of Aston Biodeterioration Centre (associate supervisor); and Drs. D. van Rest and A. J. Cochrane, at various times my IHD supervisors. I would here like to thank my collaborators, Dr. T. G. Barnes, formerly of the Biodeterioration Information Centre and now of the National Coal Board, and Dr. K. J. Seale of the Biodeterioration Information Centre; not least for their tolerance. I would also like to thank Dr. A. J. Stribling, Managing Director of Lucas Furnace Developments Limited of Wednesbury for sponsoring this work and for material assistance; the Science Research Council, for providing a maintenance grant during the first two years of the work; and the University of Aston, various casual employers and the Department of Health and Social Security for providing, between them, finance for the last year.

I also wish to acknowledge the assistance given by the following persons and organizations:

Central Government. Department of the Environment. (Central Library).
Department of Agriculture, Fisheries and Food,
especially Messrs. C. T. Riley and K. B. C. Jones; also Brian Hodgetts, Poultry Adviser, A.D.A.S., Worcester.

Local Government. (All pre-April 1974 authorities)

W. Johnson, Acting City Engineer, City and County of Bristol;

John Wilson, Chief Public Health Inspector, Chesterfield R.D.C.;

James Noble, Burgh Surveyor, Burgh of Cowdenbeath;

C. Edwards, Services Manager, Dorking and Horley R.D.C .

John W. Fletcher, County Engineer, Dumfries County Council;

Alexander Duff, County Engineer, Dunbarton County Council;

J. Scott, Manager, Cleansing Department, County of the City of Edinburgh;

C. W. P. Francis, Chief Engineer, States of Jersey Sewerage Board;

A. F. Alexander, Engineer, Surveyor and Planning Officer, Leatherhead U.D.C.;

W. R. Shirreffs, City Engineer, Leicester County Borough;

Keith J. Roberts, Local Government O.R.U., Reading RG1 4LH;

E. L. Bailey, Borough Surveyor and Water Engineer, Borough of Royal Tunbridge Wells;

V. G. Gosling, Salvage and Cleansing Superintendent, Worthing Borough;

Industrial Organizations.

British Petroleum Co. Ltd. (H. G. Warman, Chief Geologist);

British Railways Board;

Occidental International Oil Inc;

Garrett Research and Development Co. Inc., (subsidiary of above);

McIntyre Haro Ltd;

Middleton Ferris & Co;

National Farmers' Union; (especially Mr. A. T. G. Sly);

Haughley Organic Products Ltd;

U.S. Bureau of Mines;

Warren Springs Laboratory;

River and Drainage Authorities.

Association of Water Authorities;

J. G. M. Rimmer, Clerk of Severn River Authority;

Ian Drummond, Clerk of Trent River Authority;

Upper Tame Main Drainage Authority.

I wish to apologize to anyone inadvertently left out of the above list and also to thank the former City of Birmingham Salvage Department for allowing Dr. Barnes and myself to look round the Castle Bromwich incineration plant; the Biodeterioration Society and the Birmingham branch of the Conservation Society for giving me a platform on one occasion each and those staff and students of the University of Aston not associated with the project directly who made the time spent on the work so much more interesting and who themselves expressed interest.

Finally, and not least, I wish to thank my mother, who despite increasing years and deteriorating health provided background support of another kind.

CHAPTER 1: INTRODUCTION AND BACKGROUND.

Summary of Thesis.

This study begins with the proposition that wastes, especially in the quantities and concentrations in which they are generated in modern times, are both a problem and a potential source of useful materials. Techniques have been developed, on the one hand to consume such wastes in a manner that will have the least adverse effect on the environment and on the other to recycle them. This thesis will attempt to evaluate the viability of some of them and to establish the conditions under which they might be applied in actual circumstances. It will also attempt to assess the likelihood of these conditions actually arising.

The basic scheme of analysis is an argument from the general to the particular. This chapter will deal with the general historical background to this study, the historical background to modern waste and pollution problems, the definition and classification of wastes, the relationship of the economy to the biosphere and the general question of the restoration of the material balance in the main carbon cycle. A review of energy questions has been included for completeness. Chapter two will focus down onto the macro-economic questions surrounding the recycling of waste and especially onto the effect of increasing rent on the prices of the increasingly scarce primary materials for which the recycled wastes will substitute. Chapter three will deal with those aspects of recycling affecting individual firms, and organisations either undertaking the generation or handling of wastes or supplying equipment for the purpose of so doing. Chapters 4, 5 and 6 will attempt to illuminate these general principles with the particular problems of the recycling of household refuse, sewage effluent and agricultural wastes respectively. Finally, Chapter 7 will summarise and conclude the argument, adding some comment as to the value and limitations of economics in the study of technological and scientific questions such as that of the recycling and disposal of wastes.

It will be seen, during the course of this work, that while there are many economic and technical obstacles in the way of the re-use of organic wastes, the long-term position as regards both renewable and non-renewable resources is such that, when rent is taken into account, it is highly likely that such wastes will be re-used, even without the added impetus of environmental costs being passed back onto the producer of the waste.

It was early decided to concentrate on one category of waste; the low-value organic kind. There were several reasons:

(i) firstly, the industrial sponsor of this thesis, Lucas Furnace Developments Limited of Wednesbury was initially interested in the reclamation of municipal refuse by composting. No attempt was made by this firm to influence the conclusions of this research, which in the light of the firm's interest were negative;

(ii) the disciplinary interests of Dr. H. O. W. Eggins, associate supervisor and head of the University of Aston Biodeterioration Information Centre, who also supervised the projects of the author's erstwhile colleagues and fellow-students, Drs. T. G. Barnes and K. J. Seal, and those of Drs. Barnes and Seal themselves were micro-biological. It was natural that work should concentrate on bio-degradeable wastes;

(iii) these materials are not intrinsically rare, as, for example are copper and gold; but they are vital for the manner in which they are combined. In a very real sense, these are the materials needed for the maintenance of life.

Inorganic wastes have not been totally ignored; certainly, "organic" wastes derived from oil or coal, such as plastics, deserve inclusion despite their low or non-biodegradeability. However, higher value wastes, particularly metals, do not come within the scope of this work; there already is a market. It is the low value and marginal value wastes, left largely unreclaimed in periods of low prices, that have created the pollution problems that have attracted so much public attention; and as population increases over the world, and with it the scarcity of primary resources, the materials at present disposed of as low value organic waste will be needed. This is the first major proposition.

The second major proposition is, of course, that micro-biological techniques applied to separates single streams of waste may play a major role in the reclamation of these wastes. In some cases, micro-biodegradation may be the only method.

Mathematical treatments have been avoided, except where necessary to the argument.

Historical Background.

This thesis - and many works of much greater importance - would not have been written had it not been for a whole series of changes in Western economic and social thought in the mid and late 1960's. From the viewpoint that economic growth defined as the real annual increase in per capita national income, or even per-capita gross national product, was the overriding goal of economic policy and the hallmark of economic virtue, informed and enlightened opinion has moved to the view that per-capita gross domestic product is an inadequate and dangerously misleading indicator of economic welfare; in some circles, such as those economists subscribing to the 'Blueprint for Survival' (1) the term has been dubbed the 'gross' product in the pejorative sense. These extremists, such as Mishan and Boulding, argue that economic growth, other than that naturally resulting from technological progress, should cease forthwith, because of the deleterious effect on the environment; most others, however, would subscribe to a more moderate viewpoint. Simple growth will still be needed to raise the very low standard of living in the developing countries to a tolerable level; in the developed countries, at least, the economy may well have to be stabilized at a high level equilibrium determined by resource scarcity and pollution levels - developed countries being those that may enter upon that happy economic state as well as those that are presently in it. Meanwhile, more attention will have to be paid to the quality of economic growth as well as the quantity, in order to minimize the very real costs of economic growth to society. "Growth at any price" has gone out of favour. It is worthwhile summarizing the reasons for this change.

The concept of economic growth is comparatively recent. The economic models of the early classicists were essentially static; the idea of dynamism, of economic evolution was introduced by late nineteenth-century economic historians such as Arnold Toynbee (2) and J. Thorold Rogers (3). Toynbee - not to be confused with his nephew - introduced the term "industrial revolution" into currency to describe the technological economic process which Britain had been undergoing through the late eighteenth and early nineteenth centuries; the statistical compilations of Thorold Rogers and others showed that current growth-rates (1893) could not be extrapolated back in time for more than a limited period without lowering the standard of life of the mass of people below the starvation line - hence paving the way for the Rostovian (4) concept of the "economic take-off", or transition from the static, traditionalist, agrarian (or even hunter-gatherer) economy to the dynamic, "progressive", industrial economy, a process which not only involves large inputs of physical capital and technical know-how, but also an extensive remodelling of social institutions and individual psychological attitudes. The work of Keynes introduced the concept of national income to the world outside academic circles; Harrod and others gave the mathematical concept of economic growth its place in economic theory. It appears a little surprising, however, that in 1954, W. Arthur Lewis could still preface his "Theory of Economic Growth" with the remark that economists had paid little attention to growth from the middle of the nineteenth century onwards. The position is now very different.

Keynes, however, would have rejected the bastard version of his "General Theory" and the bastard ideas on growth that became current in non-academic and especially political circles after the Second World War. Keynes' model, or the simplified version of it, suggests that in order to stimulate a depressed economy, either private or public consumption has to be stimulated. Public consumption may either be in the civilian or military fields. After re-armament and war had demonstrated the soundness of this aspect of the Keynesian model through stimulated activity via military consumption, civilian business, first in the U.S.A. and then, as wartime shortages and dislocations were overcome, in Western Europe and Japan, turned to stimulating demand for its consumer products by "creating more desire" (5), using advertising aimed at making the consumer dissatisfied with his existing stock of consumer goods, by utilizing such psychological levers as status, the desire to be up-to-date and Freudian sex-drives, but most importantly of all, by exploiting the unsatisfied psychological and spiritual wants that lay behind the new-found affluence. As is often the case, the artist anticipated the economist or the technologist. Aldous Huxley, in "Brave New World" (6) put into the mouth of the World Controller, Mustapha Mond the statement 'But industrial civilisation is only possible when there is no self-denial. Self-indulgence up to the very limits of economics and hygiene. Otherwise the wheels stop turning.

This vulgar consumerism had to stop. The attempt to increase human happiness by increasing abundance is subject to diminishing returns both with respect to increasing abundance and the passage of time; the anciently-known truth that it is useless to satisfy psycho-spiritual wants by material means was to be re-learnt. By the mid-sixties, a new generation was coming to adulthood, born into affluence, taking it for granted and hence more disposed to criticize it than their elders who, born into poverty, were at first inclined to marvel at it. Advertising, like any other stimulant, is subject to diminishing returns with time and dosage; and real or alleged practises of "planned obsolescence" - the designing-in of short lifetimes into products to increase turnover over time - brought whole industries into disrepute, notably motor vehicles. It also seems that Western economies may also be reaching the maximum amount of personal consumption that individuals can indulge in; according to Donald Schon (7), industry is finding it increasingly difficult to identify or create new demands to satisfy - possibly because the relatively conservative consumer-durable industries are fast running out of technology. Hence a groundswell of disillusion with the consumer economy. From the point of view of this thesis, however, two factors are of greatest importance - increasing resource scarcity and the effect upon the environment and people of accumulations of waste on land, in fresh or seawater, or in the air, which when translated into economic terms is defined as "negative spillover".

Pollution - A Historical Perspective.

Concern about pollution and negative spillovers from industry into the environment is as old as industrialism. Friedrich Engels (9) was as sensitive to the environment created in the Manchester of 1842 as any modern environmentalist could have been, and he was by no means alone in his time; Wordsworth's opposition to railway construction in the Lake District is well known; the Victorians generally displayed a higher level of environmental conscieousness than they are generally given credit for - note the best of their architecture. Their "Red Flag Act" of 1876, which virtually prohibited the use of motor vehicles (apart from steam trams) on the roads was partly inspired by the same concern for the environment; when that legislation was repealed, Edwardians showed concern over early motor pollution - particularly over noise and mud thrown up by what was then a rich man's toy (9). Some of this concern - like much landowners' opposition to railway building - was open to the same objections as much environmentalism is nowadays; that it is the work of established, privileged persons or groups of people, wishing to maintain the present status quo or return to some, perhaps mythical status quo ante.

Quantification has been attempted all this century. Using such data as was gained by computing the extra cost of soap and detergent used in polluted areas and the cost of eroded stonework and other materials, the cost of air-pollution in London in 1912 was estimated at £1 4s. per head per year; in Manchester in the same year it was estimated at £1+ per head per annum, and in Pittsburg, Penna. estimated costs were $20 or £4 per head per annum at that rate of exchange. (10). More complex costs, such as those of impaired health or degraded aesthetic environment were not attempted until recently; and it is symptomatic that it should have taken the smog of 1952 to stimulate effective legislation aimed at reducing coal-smoke pollution. There is no doubt that the above figures were gross underestimates.

The explosion of environmental concern which took place in the mid nineteen-sixties was detonated by the combination of several influential writings, such as Rachel Carson's "Silent Spring", dealing with the effect of pesticide applications on bird populations and Kenneth Boulding's concept of "Spaceship Earth" with the occurrence of several spectacular pollution disasters (the eutrophication and pollution of Lake Erie, U.S.A., albeit somewhat exaggerated; mercury poisoning at Minimata Bay, Japan; gross atmospheric pollution and smog in Tokyo, Japan; the pollution of Lake Baikal in the U.S.S.R. by paper mill effluent and the gross pollution of the Rhine by chemical effluent, to the point where a journalist in 1971 developed a photographic film in the water) and the evidence concerning gross miscalculations of negative spillover resulting from large technological projects (e.g. the destruction of the Egyptian sardine fishery, and increased Egyptian dependence on artificial fertiliser, caused by the entrapment of the Nile silt behind the Aswan High Dam). Added to this was the evidence of general environmental degradation on the increase in all industrialised countries, much of which was attributable to that erstwhile symbol of progress and affluence, the mass-production motor car, which was thereupon demoted to being a demon symbol of all that was undesirable in the consumer economy; the optimistic belief that increasing per-capita GNP would by itself abolish poverty and relieve social strains was also falsified by events. Not unimportant was the political need, after 1968, of radicals for a new cudgel to beat the economic establishment with, as the Vietnam war was defused as a political issue. Hence 'pollution' and 'conservation' became political issues as never before.

The economies that found themselves in most difficulties as regards negative spillover from pollution were those who had most heavily subscribed to the 'work ethic', 'protestant ethic', 'capitalist ethic', or most accurate description of all, the 'production ethic'. This was especially true of the U.S.A., where there was no strong challenge to the production ethic from either a right-wing opposition based upon criteria of husbandry of land and other resources for future generations of aristocratic ideals of the good life or from a left-wing opposition concerned with the effects of industrialist ethics on the welfare of working people; and where there was also a remnant of the 'pioneer mentality' still surviving after the pioneer era had ended. Much the same is true of Australia and, in a different context, Japan; it is in these countries that the most vocal protests have been made and which face the largest expenditures for removing accumulated negative spillovers (11).

However, from empirical observation, there appears no necessary correlation between the volume or type of pollution and per-capita national income; highly-industrialized economies will tend to produce more waste per capita, but the volume and character of the wastes produced will depend on the technologies employed in that particular economy and the mix of industries and pollution will, to a large extent, depend on the political will or ability of the State concerned to control emissions. Generally speaking, Switzerland, Sweden, Norway and possibly New Zealand may be cited as relatively 'clean' high-income countries, whereas some cities in low-income countries compare with the worst examples in the developed world - Caracas, Venezuela, has atmospheric lead levels comparable with New York; Santiago, Chile, has automotive pollution comparable with Los Angeles and the two main Turkish cities, Istanbul and Ankara, the former ranking as the poorest city in Europe, have atmospheric pollution levels higher than in industrial Europe (12). The centrally-planned Communist economies of eastern Europe have done no better, on the whole, than western capitalism; for they, too, have placed paramount importance on production. Nevertheless, the existence of massive pollution anywhere only underlines the need to take these negative spillovers into account and to consider the quality as well as the quantity of economic growth in future.

At the same time, it became obvious that reserves of many important non-renewable commodites, notably oil, were being depleted at a dangerously high rate - and that many biological resources were being exploited beyond their replacement rate. In the long run, resource shortages may prove far more important than negative spillovers in encouraging waste utilization and recycling. The environmentalists have tended to adopt recycling as a panacea; it is hoped to examine the possibilities and limitations of recycling in a realistic manner.

Defining "Wastes".

Hard and fast definitions of 'waste' are difficult to formulate. The word seems to be derived from an ancient root preceding both Latin and German; Latin has the verb 'vastare', to lay waste (in its military connotation - hence devastate) and Middle High German has 'waste'. The modern German 'Wuste' means a desert. In a medieval context, the 'waste' consisted of the untilled and uncleared land around the village that lay within the vill or parish and over which the villagers had rights of rough grazing, pig-keeping, the cutting of turf, wood or osiers etc., and which contributed much to the manorial economy. As populations grew, more land was taken into cultivation; and increasingly from the end of the Middle Ages, the better pasture was enclosed and taken into individual holdings. Wasteland then became synonymous with unproductive or submarginal land; in legal usage, the Latin usage 'vastare' was adopted to denote the "waste" of an estate, meaning the dissipation of its resources by profligacy or neglect (e.g. failure to maintain buildings, drainage or cultivation), a usage that spread from real estate to other assets, tangible or intangible, to create the pejorative meaning of the word "waste" denoting the inefficient utilization of resources or their dissipation by profligacy or neglect. However, the 'waste' that is under discussion here also has its root in the connotation, to lay waste (vastare) or spoil; for waste materials are those materials that are of no further utility to the organism or process that has used or produced them, having been 'spoiled' in use.

Strictly speaking, a waste should only be a commodity which is produced jointly with the main good or service and has no utility for the producer; indeed, which imposes a cost either on the producer or on society or the environment for its disposal. 'Utility' here carries its widest sense, including market value. A "waste" that can be marketed or disposed of at zero or negative cost to both generator and society is not strictly a waste, but a by-product. However, this definition is only useful to distinguish between waste-products and main, or by-products of a firm, person, or process; it would invalidate the title of this work and the terms "waste trade", "waste merchant", or "waste marketing" in common use if it were to be adhered to too strictly. A looser, but more useable definition, would be that waste materials are thos that, having been once used in the production of a good or service, whether for sale or internal consumption, cannot be used again by that organisation and which must be passed to another organisation or organism for safe disposal, or further use.

Wastes can be either process wastes - that which is produced along with the main product during the production process - or terminal wastes, those which arise from the wearing-out or obsolescence of the fixed capital used. "Scrap" is usually used to denote these terminal wastes, especially metals derived from the break-up of obsolete plant or containers; metallic scrap, being readily marketable except where generated at a remote distance from a processing plant or when contaminated by other components, will not be dealt with in great detail. Some scrap is non-metallic; germanium and silicon from electronic scrap or rubber from scrap tyres, for example; and some process wastes, especially offcuts, swarf and turnings from the engineering industry, are metallic. Metals mainly present a problem from the point of view of this work in the form of diluted, finely divided wastes, in concentrations high enough to be toxic but in too low a concentration to warrant recovery by normal accounting criteria.

Classification.

For our purposes wastes can be classified into metals, other inorganic wastes, fossil-derived organics and biosphere-derived organics.

Metals have been partly dealt with above. The difference between these and other categories is that in many cases, though not all, scrap metal, offcuts and swarf can be returned to the melt and be used indistinguishably from virgin metal. Even where this is not so, due to alloying or contamination (especially with aluminium) there are usually lower-grade secondary uses for the material. With metals, it is the metallic elements themselves that are geochemically comparatively rare (except perhaps for iron and aluminium) and economically scarce; the more common metals tend to be the more chemically reactive and hence require large quantities of energy to reduce them from their ores; whereas those that are easy to reduce and particularly those that occur native are rare, scarce in relation to demand and therefore command a high price. Since the cost in energy of using reclaimed metals, especially the reclaimed common metals, is much lower than that of reduction from ore and those metals in the second group are so scarce, there is generally little marketing problem with metallic scrap apart from those of intermixture with other materials that may detract from quality - known as "pernicious contraries" - and problems of quantities available at any one time. This last will be dealt with below, when patterns of recycling are considered.

In contrast, the component elements of non-metallic wastes are not in general rare or scarce; their economic value depends on their physical or chemical combination. They are therefore far less easy to recycle, as the processes of manufacture for their first use may have altered their composition in such a way that they cannot be considered as virgin material or equivalent, or even used as lower-grade applications of their first use. Inorganic non-metal wastes will not be dealt with in great detail. Glass can be recycled, but problems of contamination arise, especially with different colours of glass and the primary materials are common and widespread; therefore secondary uses may be more appropriate. Fly-ash, building rubble, potsherd and other ceramic wastes have found secondary uses. Chemical industry wastes pose their own, well-known pollution hazards; iron oxides can cause a nuisance. At worst, most of these wastes, if not liable to pollute ground water, can be used as a superior landfill to municipal refuse.

Organic wastes, on which, for reasons given in Page 1, discussion will be concentrated, are pre-eminent examples of economically scarce combinations of very common elements - carbon, hydrogen, oxygen, nitrogen, sulphur, phosphorous, sodium plus some trace elements combined into complex materials; foodstuffs, fabrics and structural materials, fuels and lubricants. Organic wastes have to be divided into those based on the biosphere - i.e. on crops of plants or animals - and into those based on the "fossil biosphere" - oil and coal. The stress will be on the biosphere-derived wastes, as these are derived from a self-renewable resource and are biodegradeable; whereas the oil or coal-based wastes are derived from a non-renewing resource and, while some of these products are biodegradeable, many others, including most plastics, are either non-biodegradeable or are extremely resistant to biodegradation. This means that recycling and disposal processes will have to be non-biological; but they cannot be neglected in work largely devoted to biodegradeable wastes, since they often act as substitutes for biosphere products and often occur as intermixtures with them. In mixed wastes, too, plastics, for example, are very difficult to sort from paper, especially by mechanical means. However, most of our work will be on biosphere-derived, biodegradeable substances.

Biological resources are renewable; but the rate of renewal is subject to growth rate, reproduction rate, the extent to which the resource is renewed by human agency (e.g. forest replanting) and above all on the superficial area of land devoted to that biological resource. Most crops have an absolute limit on the extent of their cultivation dictated by climate and soil type; within these limits, there are economic limitations concerned with returns from alternative land uses, existence of markets, communications etc. Now only the biosphere can produce food; despite the notoriously variable nature of population forecasts, it is reasonably supposed by the United Nations and other bodies that world population may double from its present 3500 million to 7000 million by the year 2000 (13) and therefore there will be increasing pressure to convert more of the world's cultivable lands from the production of timber, textile fibres, vegetable oils, rubber and other non-edible commodities to foodstuffs, and where climatic conditions are favourable, from animal husbandry to the raising of arable crops. This will be especially true of the developing countries. Admittedly, some land will always be only usable for forestry or pasture; and plant-breeding is still giving rise to improvements in productivity. However, it is expected that this demand for food, plus increased potential demand for commodities by the increasing population, will mean increasing scarcities of these commodities and hence favourable conditions for the re-use of biosphere waste materials.

Furthermore, the great demand on 'fossil biosphere' resources for use as an energy source, and the increasing scarcity and uncertainty of supply of both coal and more especially petroleum indicates that it will no longer be automatically possible to consider the use of coal- or petroleum-based substitutes for biosphere commodities as it has been in the recent past. One reason for the recent neglect of waste-based biological processes has been the availability of petroleum at very low 'spot' prices and the tendency to assume that these prices would hold for all time, of which more in the next chapter; given, of course, the relative homogeneity of petroleum substrates as against most waste streams. This leaves biodegradeable wastes as the last under-exploited resource available for organic materials.

As has been mentioned above, because these materials depend on their combination rather than on the elements of which they are composed, they often cannot be recycled into the virgin stream. The fibres of paper, for example, are shortened with each recycling; although this can be carried on for many revolutions, the fifth recycle is generally the last, as the shortened fibres are then very suitable for toilet paper, absorptive tissues, cigarette paper and papier-mache containers, most or all of which by nature are one-trip uses. This means that a secondary use is involved or the materials are returned to the environment. Where a process involving a living organism is concerned, true recycling is often impracticable; it will be shown later that it is impracticable, to all intents and purposes, to recycle animal wastes directly back to the generating animal.

Comparison between the Biosphere and the Economy.

The comparison that the biosphere recycles nearly all its materials and the economy uses them in a linear fashion is too commonplace to be stressed here. More interesting is the fact that the biosphere is based on some very common elements - hydrogen, carbon, oxygen, nitrogen, sulphur and phosphorous as main components with trace minerals as essential minor materials; whereas some of the major materials used by the economy are geochemically rare - copper or zinc, for example. For the one non-recyclable commodity, energy, the biosphere depends on the sun, via photosynthesis; the sun has an expected remaining life of approximately 4×10^9 years, virtually infinite from a human point of view, whereas human fossil-fuel energy sources have a very short expected life-time - in the case of petroleum, some 35 years from the time of writing, (1974). Therefore, the biosphere is based on a very stable foundation, whereas the human industrial economy is not only based on one that is unstable, but is bound to be short-lived unless its basis is changed.

Environmentalists have often preached about converting the economy into a cyclical process, but what is overlooked is that the economy is basically a technologized extension of the process by which man feeds himself. In nature, an animal does not recycle its own food; it takes in food either directly from plants or indirectly be eating animals that have eaten plants. Its excreta - i.e. its process waste - and its decay products, i.e. its terminal waste, should it not be eaten itself, are utilised by saphrophytic micro-organisms, cophrophylic animals and some species of plants to provide energy and material for themselves and to return materials to their primary reservoirs. It so happens that some of these organisms are eaten and the material thereby returned to the main stream - of which more below; but it remains that the photosynthetic, respiratory and digestive processes of individual species are one-way, though the biosphere is cyclical. Likewise, man's economy is one-way in its use of material; and it should be remembered that for most of human history, man was more or less an animal among animals, whose food, clothing, building materials and wooden tool materials were taken from the biosphere and which were recycled by the biosphere when their useful life was over. Stone tools had a neutral effect; they were made from surface-lying pebbles and when discarded they reverted to being surface-lying pebbles. Fire-raising was the only activity really atypical of other animal species, but fires also occur naturally and the environmental effects of deliberate or accidental conflagrations were often short-lived. Stone-chipping, however, led onto industry. It became gradually recognised that the best stones were found in the bedrock, in certain localities. According to a hypothesis of Jane Jacobs (14), the first fixed settlements were those of miners, although, as at Skara Brae in Orkney, fishing could have the same effect. Fixed settlements encouraged the development of agriculture and domestication of livestock; agriculture in turn encouraged more fixed settlements. These fixed settlements created the first environmental problems; assumulation of pathogen- and vector-breeding organic wastes in small areas, in quantities too large for ordinary decay processes to remove safely. These organic wastes - human excreta, dead animals, waste from animal slaughter, spoiled food, used bedding, - remained the core of the waste problems of all communities up to the time of the Industrial Revolution.

These problems took a long time to tackle. Up until comparatively recently, even in Europe, disease tended to be ascribed to the operation of malignant spirits or "the will of God", despite the efforts of some religions such as early Judaism to preach sanitation as part of their 'religious' doctrines. Because of the negative net reproduction rates of anciant and medieval towns, stemming largely from the high death-rate following from their insanitary condition, the majority of town-dwellers were first or second-generation - mostly, therefore, in-migrating peasants with little knowledge of city-dwelling. In this environment it is not surprising that it took a long time and many deaths and plagues before people learnt to abandon such practices as leaving dead livestock in the street, excreting and urinating in the street, in water-courses used to supply drinking water, and even in living-rooms (the latter a feature even of the highest circles of society), or even occasionally threatening the economic base of their towns by choking river-navigations with refuse, as happened at medieval Norwich (15).

Early fixed communities of large size also created the first resource problems. Ignorantly-practised agriculture caused loss of fertility and soil erosion; forests were stripped causing more erosion, both for the sake of their timber and for the land on which they stood; this led to an increased need for imports, therefore for trade in other commodities. The need to secure resources and eliminate competition, encouraged wars; in the end, such resource problems, from first encouraging the growth of empires, led to their downfall. For it was the central areas of the empires that bore the brunt of the burden of empire; and once the technological and organizational advantages that the imperial centres had once had over the outer provinces and the outer barbarians, that burden became insupportable.

Although the Industrial Revolution, by creating even larger agglomerations of people, at first exacerbated the earlier environmental problems and led to very large outbreaks of cholera in British industrial towns (e.g. in 1821 and 1831 in London), and added new pollutions of its own - coal-smoke pollution and pollution of water by process wastes, for example; it did provide themeans of solving the earlier problems, however adventitiously; cast-iron pipes for drainage and water-supply, fired brick to replace the cob, mud, lathe-and-plaster and turf that had been the main building materials for the common people's housing outside the immediate vicinity of stone quarries; washable textiles for underwear and cheap cotton textiles; cheap soap and detergent; railways to carry milk into town, thus obviating the need to stable cattle in cities with all the insanitary implications thereof. More importantly, the revolution in intellectual outlook, which began in the mid-seventeenth century, preceeded the industrial revolution, accompanied it and ended by merging with it, provided the understanding of the disease problems of city dwelling and the means of overcoming them; the evil spirits gave way to the pathogenic micro-organisms.

This intellectual outlook, which basically aims at a rational understanding not only of the physical universe but of man's mental universe as well, can also serve in finding a solution to the pollution and resource problems that have been created by the evolution of industry and the economy since; and could possibly anticipate problems that could arise, if it is allowed to. This is often overlooked by those who blame 'technology' for all these problems.

Science and technology, however, cannot act on their own. The word "technology" is derived from the Greek "technos", a skill or craft; and skills or crafts can no more operate without direction than a chisel can carve itself a statue without direction from a sculptor. There is no validity in the idea of a "technological fix", that "technology will provide the answers", regardless. The various technologies will have a very important role to play, but the bases of many of these situations lie as much in the economic and social spheres as they do in the technical. Hence a multidisciplinary approach is essential. For example, if technological research is to be applied to the elimination of a particular pollutant, there must be some incentive to do so; and this is best done, by pressure on the generators exerted by the imposition of some form of cost.

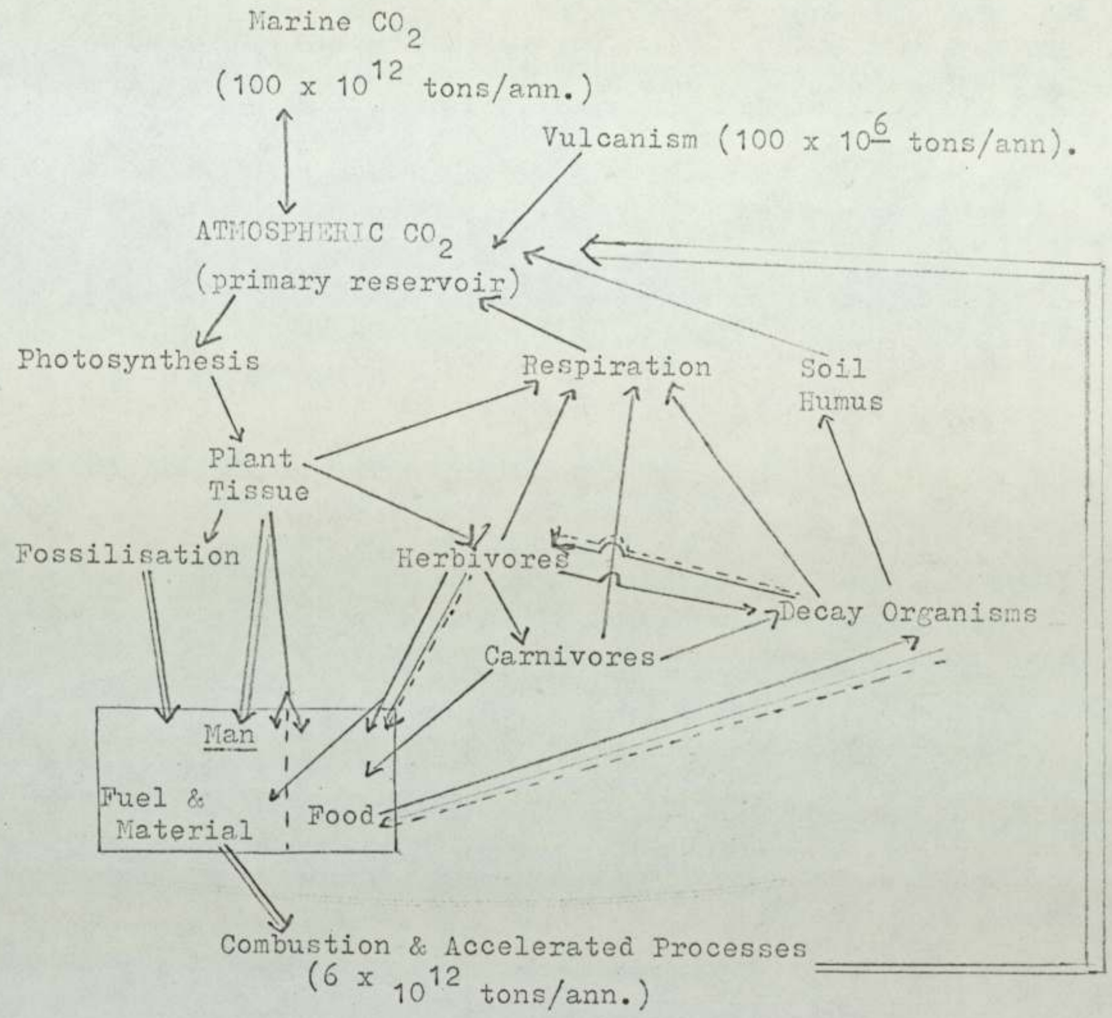
Finally - and this is an important consideration from the viewpoint of this work - there is the responsibility for the maintenance of the biosphere. Man is no longer one mammal amongst others; to a large, though not yet to a complete extent, man has established control over the biosphere. This is not merely a question of the preservation of certain species of mammals and birds whose ecological niches have been largely destroyed by human activity; as well as supplying commodities whose value will increase as 'fossil' substitutes grow scarcer, the biosphere is the only supply of food. With human numbers at their present level and given the size of the human economy, man's future welfare increasingly depends on intelligent management of the biosphere.

The Biosphere Cycles and the Recycling of Waste.

In a cyclical system, such as the biosphere, there are no 'resources' or 'waste accumulations', but there are reservoirs around the circuit. The largest will be the reservoir of "primary" raw material - in the case of the carbon-oxygen cycle, the carbon dioxide in the atmosphere and dissolved-up in the oceans. The atmosphere is also a reservoir for oxygen released by photosynthesis, and essential for respiration; also for nitrogen, prior to fixing in the soil by bacteria. The soil and the oceans are the primary reservoir for sulphur, phosphorous, potash and other necessary minerals.

Diagram 1.1. shows, as an example, a modification of the familiar carbon-oxygen cycle, showing additional paths opened by human agency and approximate quantities, for purely illustrative purposes, as estimated by McHale (16). Now, even without the figures, it will be seen that man has accelerated the return of carbon dioxide to the primary reservoir from the other reserviors such as the living biosphere and especially from the 'fossil' biosphere without a corresponding increase in the rate of photosynthesis. Indeed, the overall photosynthesis rate may have declined owing to bad farming practice, deforestation, building-over land, pollution and other causes. Now, although the First Report of the Committee on Environmental Pollution (17) states that CO_2 proportions in the atmosphere have doubled over the last thirty years, it has been able to dismiss the idea of 'global pollution' from this source as a bogey; there is no danger of a Venus-type "greenhouse effect" causing drastic climatic changes. However, it does no good, either. Higher plants exhibit stomatal closure - closure of the stomata or the proes on the underside of the leaf - at elevated concentrations of CO_2, (18); and these are the plants of economic importance to man. Photosynthetic algae, particularly the ancient blue-green varieties (such as the Oscillatoriaceae, fossil examples of which were found in the Gunflint chert laid down some 2500 million years ago) may well benefit (19); but many modern-type plants of economic importance photo-respire - that is, return CO_2 to the atmosphere above certain threshold intensities of sunlight (20). Hence it is of importance to retain carbon in the living portions of the cycle if the biosphere is not to shrink.

The position is even more critical with the soil-derived nutrients, particularly with the basic nitrogen, potash and especially phosphates. Nitrogen is fixed from the atmosphere by nitrogen-fixing bacteria, as soluble nitrate, usable by plants through their root system. It is recycled back to the soil by excretion from plants and by biodegradation of dead plant matter; also via animal faeces and urine and the biodegradation of dead animals. There is also a route back to the atmosphere via losses as ammonia and by the activities of denitrifying bacteria. Potash is derived from underlying rocks, with a trace contribution, as with phosphate, from dissolved salts carried inland from the sea in rainwater and - near coastal regions - spray. In the case of potash and phosphate, there is a long-term cycle, involving evaporite deposits - left behind by the drying-up, under arid conditions, of ancient seas and inland-drainage areas - but this occurs over geological time. Sulphur also occurs as a marine-spray item; sulphur deficiencies mainly occur in continental interiors and not in maritime regions, volcanic areas or downwind from centres of heavy industry, which also liberate sulphur. In addition to all these, agriculture tends to encourage a loss of nutrients from the soil at an accelerated rate; it has long been known that soil fertilities have to be maintained by applications of some form of fertiliser. Traditionally these have been animal or vegetable wastes; but more recently, in the developed countries, for reasons of labour-cost, increasing use has been made of inorganic fertilisers. Several varieties of crop plants have also been bred, which yield heavily when intensively fed with nitrogenous fertiliser. However, these fertilisers are mainly derived from non-renewable resources; rock-phosphate, Diagram 1.1. (Facing p.26).



Normal Path (60 x 10^{12} tons /ann) ⟶

Man-made Return Path ⟹

Suggested Cross-Link ⇢

Source of rough estimates: M^c^Hale, "World Facts and Trends," "Futures," v.3 no.3 Sept 1971 especially, is scarce, has a limited life and is liable to geographical monopoly. Hence, there is a greater need

(1) for recycling, and

(2) for retaining biosphere materials in the economically useful portion of the biosphere for as long as possible.

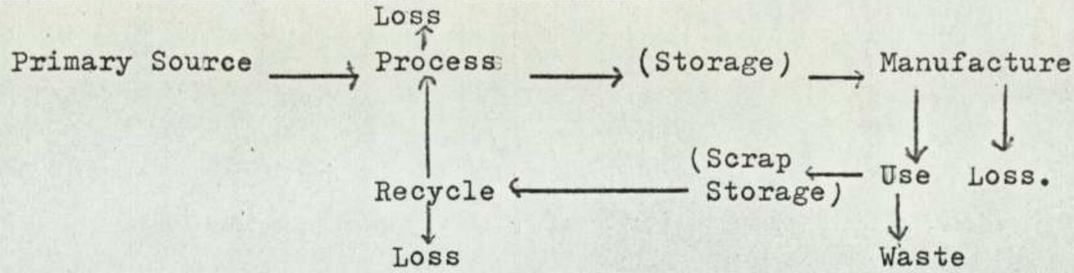
It will be noted from Diagram 1.1. that there is a loop back from the 'decay' side of the cycle, via animals eating saphrophytes and cophrophilic animals, to the 'metabolic' (or outward) side. It is this loop that will have to be reinforced in order that carbon and other biosphere materials may be more effectively utilised, as will be shown in the chapters on town waste and farm-animal waste.

Cycles in the Economy.

Economic cycles can take more than one form. Completely closed loops are impossible, since there is bound to be some loss. The nearest approximation is shown in Diagram 1.2a, a partially closed loop with material being added from a primary source on one side and shown as lost at one point on the other. In fact the loss shown is the aggregate loss for all leakage points in the cycle, shown at one point for simplicity. This is the characteristic metal cycle and is applicable where the waste can be fed into the primary stream. The dynamics of this cycle will be discussed in Chapter 3. For those materials that cannot be added to the primary stream the 'fan' distribution as shown in Diagram 1.2b is more appropriate. The efficiency of recycling, here is the proportion of material leaving the high-grade uses that is utilised in lower grades. In this diagram, the process is shown as linear, but 'loops' in the lower-grades are not

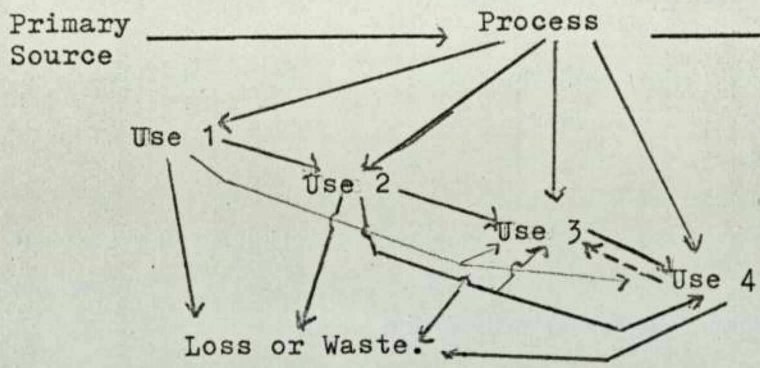
Diagram 1.2. Cycles of Materials in the Economy.

(a)



Bracketed stages are optional.

(b)

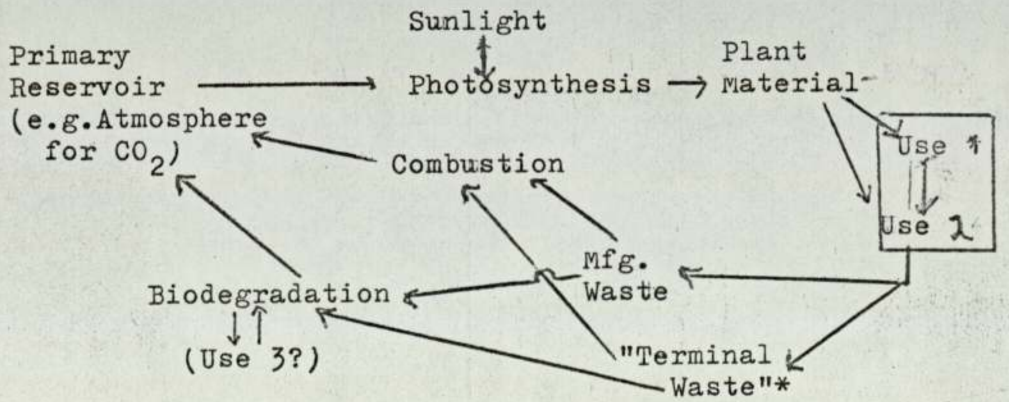


Uses ranked in descending order of added value. Dotted line indicates possible recycling between low-value uses.

(c)

Primary Source ⟶ Use ⟶ Waste.

(d)



*Terminal waste is material that has fallen out of use at the termination of the useful life of the object concerned.

excluded; the material proceeds from high-grade uses to low-grade and eventually falls out as waste. Since material is retained in the system for a longer period, however, it is still superior to an all loss application, (Diagram 2c).

Diagram 1.2d shows the case of a biosphere product where a portion of the natural cycle or a living organism is used as part of the recycling process, as would be necessary with digestion wastes (animal) and some plant and non-food wastes. Speed of recycling is outside economic control in that, not only is the speed of biodegradation dependent on several parameters affecting the organism involved, but the rate of photosynthesis of the plant of economic importance involved will depend on plant efficiencies, solar intensity, rainfall, area planted etc. Now, over the biosphere as a whole, this productivity is fixed; and since human activity has accelerated the return path of material in the cycle without a corresponding increase in the formation of organic material, the biosphere has actually shrunk; especially some of the most economically valuable parts of it. The purpose of this thesis is to show why - and how - material abstracted from the biosphere should be retained in the economy as long as possible, and be returned to the biosphere at as early a stage in the carbon-energy cycle as possible. It is desirable that any material should be returned to the cycle at a point prior to its use by man and/or his domestic animals. Any return afterwards would involve losses of material, and all material going through the primary reservoir, which, as has been shown above, conveys little benefit. This may be done by the return loop mentioned above; whether by a macro -

or a micro organism depends on the desired product. Actinomycetes, bacteria, unicellular fungi, yeasts, complex fungi such as basidiomycetes, higher plants; unicellular animals, insects, earthworms, certain mammals; these utilise this loop and one of these may produce a desired product, from their own tissues. It is one of the functions of studies such as those that have been pursued at Aston to investigate and develop technologies for making use of this portion of the cycle. Because of the disciplinary bias of the team, the projects involve microbiological processes; but this is not to exclude any benefit that may accrue from using macro-organisms.

Energy and Fossil Fuel.

While this work is not intended to deal in energy questions, all activity depends on energy, including recylcing. Therefore, it would be pertinent to discuss energy here though not in great detail. Furthermore, the biosphere was and is still a source of energy, especially in the Third World, and oil and coal are 'fossil' fuels of biological origin.

Oil and coal can be considered as portions of a cycle, but of geological slowness; reserves of coal and petroleum must be considered non-renewable. The enormous contrast between the assured energy picture of the biosphere and the short expected lifetime of oil in particular needs no reiteration. If consumption remains stationary at 1969 levels, an equivalent of the world's presently known reserves will be used by approximately 2005 (21); since these figures were produced, reserves have increased, so has consumption. Prospects for coal are somewhat longer - if coal had to substitute for petroleum, present reserves would last 50 years; if not, up to 500 years (22). Energy reserve estimates, however, are notoriously uncertain; coal has attracted little interest as a mineral since 1945, and little fresh prospecting has been done. Reserves are not accurately known in many areas; China's last publication of reserves was in 1913; the U.S.S.R's reserves are unknown but enormous; Australia and South America are not well explored; even the British Isles has recently produced major discoveries in the shape of the northward extension of the Barnsley seam and the indications of huge reserves of coal under the North Sea. However, the North Sea reserves are inaccessible by present technology and are still finite, despite their vast size.

In further chapters, especially Chapter 4 on municipal refuse, there will be dealt with the temptation to use organic wastes as a fuel supply. This is an economic snare; even at current energy price levels, current substitution values for the recycled wastes are in many cases higher. Even disregarding this suspect criterion, there is the low calorific value of these wastes to consider and the small quantity and therefore potential energy supply in relation to demand. In any case, any major shortage of energy will restrict production, therefore consumption, therefore waste generation.

Some of the other alternatives seem problematical. Nuclear fission, the most-touted alternative at the present time, carries certain well-publicised risks (24). The chief safety questions are whether the probability of a serious escape of radioactive material in the case of any one reactor will be low enough when several thousand of the same type of reactor may be operating simultaneously, or whether it is possible to prevent the diversion of fissionable material or radioactive waste for military or criminal purposes, particularly by maverick governments. The supply of uranium is very price-sensitive and reserves are therefore estimated (a) at a given range of price, and (b) making alternative assumptions as to the use of conventional or breeder reactors. Estimates of lifetime range from 100 to 700 years, depending on alternative assumptions as to technology and price level, but all must be treated with caution. Exploration has not been exhaustive and some countries' reserves are a State secret.

Solar energy has been advocated as a power source; its comparative cleanliness appeals to environmentalists and its enormous total theoretical potential - 10.3×10^{16} watts on the earth's surface at a flux of 1.94 calories/$cm_{2/min.}$) is such that serious attention is warranted. The amounts of solar energy reaching the earth's surface during a week is roughly equivalent to the energy-content of the world's known fossil-fuel reserves; and while some areas - especially the tropical deserts - are better placed to utilize this energy than others, there are no such geographic monopolies as exist with oil and coal. There are serious disadvantages with known technology, however. There are no economies of scale in building large units; such large areas of land would have to be covered that the capital and maintenance cost of large collecting elements would be prohibitive. Comparatively small units would have to be used; which would mean reversing the whole trend of industrial economies, which has been towards large, highly centralised production units, especially in energy, and particularly in electricity generation. A further consideration in this respect is that in many areas suitable land for the purpose is scarce; solar energy is already heavily utilized, via photosynthesis, for producing crops of various sorts; including timber, in some parts of the Third World, that is still extensively used for domestic fuel. The most suitable land is land or area that cannot be used for crop production - arid areas with high incident sunlight or roofs of buildings in cities, for example. Now, for historical reasons, the world's major industrial areas have mostly evolved in high latitudes, with comparatively high proportions of cloud-cover and land used by agrarian and other industrial uses - north-east U.S.A. and eastern Canada; Western and Northern Europe, especially Scandinavia; the U.S.S.R., especially the industrial regions of Moscow, Leningrad, and Siberia; North China and Japan. In contrast, the south-western U.S.A., Australia, Israel and South Africa, with Iran a possible transition case, are the only desert regions that are industrial states or parts of industrial states which therefore have access to the technological know-how and capital required to develop such systems; and to those industrial areas within or near the Arctic Circle, solar energy would be of little utility whatsoever, if the only method of using it were to be by direct generation of heat or electricity. Furthermore, most areas have not the east-west spread required to increase the 'day-length' via feeding into an east-west grid system. Nevertheless there are current possibilities for its use to provide energy for the regulation of the environment inside buildings, water heating and as a supplement to other forms of energy.

Hottel and Howard (26) came to very pessimistic conclusions as to the costs of solar energy, but these were based on the technology and the prices of alternative fuels of 1971. The technology of solar energy is at a very early stage; and rising oil prices have already overtaken some of their conclusions. The investigation of the properties of flat black surfaces and of photo-voltaic cells has not proceeded far enough for a true assessment of their possibilities.

Still more is this true of the utilisation of indirect solar energy - its use to manufacture a fuel that can be transported. This could be done either by a photochemical process (the photolysis of water to form hydrogen has been suggested) or, perhaps more simply, by the use of photosynthesis in specially-designed circumstances. Of course, biosphere products have been burnt as fuel for thousands of years, but the overall efficiency of energy entrapment using ligniferous tissue is too low to be of utility on the scale required; in addition, it competes with food production for suitable land. The use of micro-biological processes may be considered. Green algae, especially Chlorella spp. have the highest photosynthetic efficiency, in the sense of biomass production/area/time of any group of plants, and it should be possible to pyralise the product. However, Hottel and Howard consider that efficiencies here are still too low (27) - 21 % of energy recovered under glass, but only 6% when grown outside. Problems of harvesting, culture, pathology of algal species, and nutrition would have to be solved and this method of recovery would pose problems in desert regions, since water would be required. Also, the final question of species to be used and strain - since, 'wild' strains of Chlorella were used for the relevant experiments. However, despite the great difficulties involved, there is room for investigation.

Petroleum, after all, is fossil micro-organism.

Therefore, it can at least be considered that solar energy is the energy supply of last resort. For various reasons, no other natural energy source is likely to be adequate as a substitute for fossil fuel on an industrial scale.

Should thermonuclear fusion be ever proved practicable, it would not doubt eclipse all other sources as a source of stationary energy, especially for electricity generation; with a virtually inexhaustible fuel and with few of the safety hazards and none of the orimino-military hazards - to say nothing of the much-reduced waste problem - a practicable fusion technology would relieve the economy from any future energy constraints. However, though the indications seem to be positive (1974), no practicable technology is yet in sight.

Meanwhile, for reasons that will be shown in Chapter 2, Western economies have been very profligate with energy. The next chapter will also show why re-adjustment could be uncertain and painful. There is probably no absolute "shortage of energy" as such; solar energy could be obtained at costs ranging from comparability with current energy costs upwards depending on application if all else failed; there is a shortage of energy at a price that the West and the developed world as a whole has been accustomed to pay for it. It is also widely accepted that energy consumption per capita for our given standard of life can be reduced by measures well within the limits of common technology; but that is not within the scope of this work.

Conclusion.

This chapter has been devoted to introducing the topic of low-value waste recycling, defining and categorizing wastes and putting forward general ideas why re-using and recycling of biosphere-derived material should be necessary; relating the economy to the biosphere and comparing them; discussing how these materials should be recycled, in very general terms which will be particularised in subsequent chapters and briefly discussing the energy position for reasons of completeness.

In Chapter 2, a more detailed discussion of economic principles affecting recycling and disposal on the macro-economic scale, and in Chapter 3 on the micro-economic scale will be presented. In the following chapters, work relating to municipal refuse and paper, farm wastes and (briefly) sewage will be considered.

The hypotheses on which the rest of this work is based are:

(a) that the object of re-using biosphere products is to reduce pressure on resources, particularly biosphere resources such as food-producing land, forests and fisheries and also resources of 'fossil' organic material; all of which are under pressure as a result of demographic and economic growth;

(b) that, following from the above, in order to re-use these materials and to redress the balance of material flow in the biosphere, biological techniques in particular should use the cross-link described above (from the decay section into the metabolic section) to recycle wastes "upstream" from human use and not downstream, as with composting;

(c) that these materials, being valuable for the nature of their combination and not for the rarity of their elements, should not be broken down to produce energy, or any low-grade product, if it is possible to make a higher grade.

References.

(1) Particularly E. J. Mishan, who headed the anti-growth movement among British economists, and Kenneth Boulding.

(2) Arnold Toynbee, "The Industrial Revolution", 1884, re-issued in paperback by the Beacon Press, Boston, from 1956.

(3) J. Thorold Rogers, "Six Centuries of Work and Wages", London, 1884.

(4) W. W. Rostow, "The Stages of Economic Growth: A Non-Communist Manifesto", Cambridge University Press, 1960. One of the more influential little books of the high-growth era.

(P.4 line 5) W. Arthur Lewis, "Theory of Economic Growth", George Allen and Unwin, London, 1954. See Preface.

(5) Advertisement in the 'New York Times' 12th July, 1949, quoted by Jules Henry in "Culture Against Man", Tavistock Publications, 1966. Aimed at the recruitment of salesmen, this advertisement was at least a frank job description of consumer-salesmanship.

(6) Aldous Huxley, "Brave New World", 1932; 1965 Penguin edition, page 185. Some readers, with the benefit of hindsight, would add, after the word "hygiene", the words "and beyond".

(7) Donald A. Schon, "Technology and Change", New York, 1968, page 168. This does not apply to any extension of consumerism to the present Third World, to the electronics industry at present or to public consumption goods; demands for the latter are liable to continue increasing as demands continue for improvements in environmental, educational, health and other services. Military technology is not stationary either, unfortunately.

(8) F. Engels, "The Condition of the Working Classes in England", 1844.

(9) Wm. Plowden, "The Motor-Car and Politics", 1896-1970. The Bodley Head, 1971. Penguin (paperback) 1973. In early 1907 there were only 32,500 private cars registered in Britain.

(10) A. B. Meetham, "Atmospheric Pollution; its Causes and Prevention", pages 239-40.

(11) The cost of 'cleaning-up America' (i.e. removing accumulated negative spillovers) has been estimated at ∅100 x 10^9, as compared with ∅29 x 10^9 for the Apollo program; but such estimates should be used with extreme caution. Italy, scene of a cholera outbreak in 1973, has been estimated to need an expenditure of £2,000 million at 1973 values - or 8% of its GNP - over five years in order to raise standards of sewerage to those of Northern Europe, thereafter spending c.£120 million p.a. for maintenance and extension. Retro-fitting adequate sewage is far more expensive than installing a system at the time of construction of a plant or built-up area; see sewage chapter.

(12) The much lower levels of industrial activity in developing countries are compensated for by the concentration of such industry as there is around the capital city; lower levels of technology; industrial and automotive equipment is often second hand and pollutant emissions result from such equipment being both worn-out and badly maintained; government control over pollution is often non-existent or sketchy.

(13) U.N. 'high' estimate, 1968. Population forecasts must be used with extreme caution.

(14) Jane Jacobs, "The Economy of Cities", 1969, Pelican, 1972. A controversial thesis.

(15) Lynn I. Porrigo, "Plagues and Pollution in Medieval England", 'Social Science', v.46(3), June 1971.

(16) John McHale, "World Facts and Trends", Futures, Vol. 3 Non. 3. Seept, 1971.

(17) The First Report of the Committee on Environmental Pollution, H.M.S.O. 1972, Cmnd. 4585.

(18) P. M. Atterwill, "Atmospheric CO_2 and the Biosphere", Environmental Pollution, Vol. 1(4), April 1971.

(19) Some plants do respond to increased CO_2 concentrations; tomatoes do develop a marginally larger leaf area. Atmospheric enrichment of CO_2 is an established technique for the laboratory cultivation of photosynthetic algae - see Stanier et al, "General Microbiology," Macmillan, 1971, a well known introductory textbook - but the amounts used are much larger than any conceivable concentration brought about by fossil fuel burning, being about 5%. Especially since most CO_2 is recycled by plants not of economic use, there is no economic benefit in raising atmospheric CO_2 levels.

(20) C. Tudge, "The Next Green Revolution", New Scientist, Vol. 57 '838). The work described here is that of Israel Zelitch, who has highlighted photorespiration as a major contribution to photosynthetic inefficiency

in certain plants under strong sunlight. Possibly evolved to prevent over-production of material by the chloroplasts in strong light, it limits the rate of tissue-production and growth in termperate-zone crop plants such as maize.

(21) From figures given by BP's house magazine "Petroleum News", 1970. Aside from taking no account of the North Sea, North Alaskan Slope and other recent discoveries, it only shows the "proved reserves" of most countries. Oil companies only 'prove' enough to justify exploitation; and only the U.S.A. and Canada issue 'official' proved-reserve figures, so any total reserve figures must be treated with caution. Diversification away from liquid petroleum is inevitable, however, since such a large part of the reserves and current production are concentrated in the Middle East.

(22) M. King Hubbert, "Resources and Man", Freeman, 1969, pages 204-5.

(23) B. J. Skinner, "Earth Resources", Prentice-Hall, 1969, pages 123-6. The supply of uranium is very price-elastic, owing to variations in ore concentration and extraction costs.

(24) See "New Scientist", volume 57 (834) p.418 and volume 57 (835) No. 835, "Risks man dare not run". The main problem concerns the disposal of large quantities of radioactive wastes, many with half-lives longer than the life of any known civilisation, let alone institution - up to 5,000 years.

(25) B. J. Skinner, op. cit. p. 108.

(26) Hottel and Howard, "New Energy Technology; Some Facts and Assessments". MIT Press, Section 7. His Costings have been overtaken by events: (Table 7.1., page 342).

Space Heating: Cost per 10^6 BTU, 1971, with 1973 Modifications.

(In $ USA)

	Solar*	Oil '71	Oil '73	Electricity
Santa Monica, California.	1.60-1.69	1.52	2.58	4.36
Albuquerque, N. Mexico.	1.60-2.32	1.48	2.52	4.62
Phoenix, Arizona.	2.05-3.09	1.20	2.04	4.25

	Solar*	Oil '71	Oil '73	Electricity
Omaha, Nebraska.	2.45-2.98	1.18	2.01	3.24
Boston, Mass. (Suburb).	2.50-3.02	1.75	2.98	5.25
Charleston, S. Carolina.	2.55-3.56	1.26	2.12	4.22
Miami, Florida.	4.05-5.64	2.27	3.86	4.90
Seattle, Washington.	2.60-3.32	1.92	3.26	2.31

*The solar technology investigated was the simple flat-plate collector, inclined at the latitude of the site plus 15 degrees, facing south. Now, black pigments superior to conventional matt blacks, in that re-radiation is reduced, have been developed; and when Hottel and Howard were writing, photovoltaic cells had not been developed as they have been to the time of writing (1974) when such are already available commercially - or subsequent developments had not been made public. The technology of photo-voltaic cells is still in its early stages.

The 1973 oil costs are in some degree arbitrary, being based on a straight 70% cost increase. Mid-1974 prices would be expected to be higher, giving a more attractive outlook for solar energy as an auxiliary energy source in all but the least favourable areas; it should be noted that Seattle comes closest in latitude and climate to North-West Europe.

(27) Hottel and Howard, ibid., section 7. However, photosynthetic efficiencies may be improved, see Ref. 20, as with higher plants. It is most probable that algal culture, like macro-biological crops, would be more useful for materials production than energy.

CHAPTER 2: MACRO-ECONOMIC BACKGROUND TO RE-CYCLING AND DISPOSAL OF WASTES.

Introduction.

Until recently, economists, while fully cognizant of the scarcity of resources in relation to demand, did not fully investigate the relationships between resource-scarcity, rent (or quasi-rent), pollution and disposal, partly because of the difficulty of quantification involved. The problem at the heart of this technico-economic question is that, while there may be more or less reliable information as to the quantities of minerals and biosphere resources available, from which the probability of scarcities may be gauges knowing likely demand, or the long-run position of the material concerned, economies can only respond if the information presented is translated into money terms; especially if they are market economies.

A good analogy from biology is that light patterns, patterns of sound waves, smells and contacts via touch have to be converted into nerve impulses before the brain can perceive them and process the information contained therein. Converting the 'social costs' of wastes and pollutants and 'amenity' values into money terms has been one of themore difficult problems to be tackled by economics since the study became systematized. For lack of this less tangible information in the past and even at present, organisations from households, through firms to governments have made decisions that have created a situation which most observers agree is sub-optimal.

Resources and scarcities.

From its beginnings, economics has been based on the assumption that resources are finite, with the exception of the few so-called 'free goods', but the potential demand for them is infinite, like atmospheric oxygen (in areas where there is little or no pollution). Recently, attempts have been made to modify this assumption by demonstrating that most wants other than those for biological necessities may be culturally determined (1); but since throughout this work we will be dealing with acquisitive, industrialised societies we can safely accept this assumption as given. However, the environmentalist viewpoint at present is that scarcities of resources will tend to increase and are increasing because (i) the exponentially-growing world economy is creating exponentially-increasing demands for substances which were geochemically scarce anyway in many cases, and (ii) those resources are diminishing at an exponential rate as a result; it is argued that the mineral resources of the earth are becoming known in toto and that horizon-times for the exhaustion of such reserves can be calculated; no unexpected land-inputs, such as the West has been enjoying ever since the discovery of the Americas and Australasia, can be expected. (cf. "Limits to Growth" (1). Against this, many authorities in the field of mineralogy such as Professor J. J. Hawkes of Aston (2) argue that mineral resources are not accurately known at present. Even in well-surveyed areas, such as the British Isles, new discoveries can be made, such as the northern extension to the Barnsley coal seam in Yorkshire and recent discoveries of low-grade uranium in Orkney and Caithness. Less well-surveyed areas, continental shelves and oceanic basins may be expected to yield further discoveries. Furthermore, 'proved' reserves are generally understatements, since all the mining companies have any economic incentive to prove is approximately twenty-five years' extraction at the maximum rate that their capital investment will permit; 'proving' involves drilling around all sides of a deposit at close intervals to gain an accurate assessment as to quantity, an expensive process (3). Taxation systems sometimes lend to understatement (4). It may be, however that new survey technologies, particularly remote-sensing from aircraft or satellites, may provide such information on biosphere resources (crops, forests, fisheries) and mineral resources that an approximate inventory of the earth's resources may be possible.

Ricardian Rent and the Non-Renewables Resource Position.

While a knowledge of the total-resource position may be of help in planning and may also be of academic interest, the control of prices of raw materials is less objective than normative; it depends on how the resource is controlled. If there are no property rights over the resource, or those that exist are weak, and extraction is in the hands of competing extractors, whether the resource is renewable or non-renewable extractors will continue to mine the resource to the end - witness the whaling and fishing industries, the gutta-percha forests of South-East Asia, the North American pine forests. In some cases, as with minerals, extraction costs may rise as leaner ores are worked; in other cases there may be no variation in resource quality. In both cases, extraction with no return to land leads to extremely rapid resource depletion and profligate use of the material involved up to the time of exhaustion. In some cases no utility may be derived from the resource at all; witness the clearing of forest by fire in New Zealand at the end of the nineteenth century.

Marxist economies present a special case. According to Marxist economic theology, all value is based upon labour; thus land resources are treated as free goods. Unquestionably, much waste and much pollution has resulted in the Soviet Union from this attitude; but such articles of theology may in practice be discarded if inexpedient. Learning from the experience of other industrialising countries, China appears to be embarking on a programme of resource recovery (6).

Where an individual, organisation or State effectively controls the right to extract and use the resource, a return to land (in its widest sense) arises and the element of rent assumes importance. Rent is to be understood in its widest sense, including not only that accruing to the owners or the controllers of the resource, but the quasi-rent accruing to persons employed in the extraction industries (e.g. miners, petrologists, divers) according to the scarcity of their skills and the degree of their organisation. Rent has been neglected in recent discussions of this issue, perhaps because since the 1870's the sociological distinction between the landlord and the capitalist in Britain and Europe has disappeared and in the U.S.A. and other 'new' countries it never really existed. It is important, nevertheless.

Now, it is elementary, that as a resource is used-up, the remaining quantities command an increasing rent as against that already used. If R is the rent, k is a constant, and Qt is the original quantity and Qu is the quantity that has

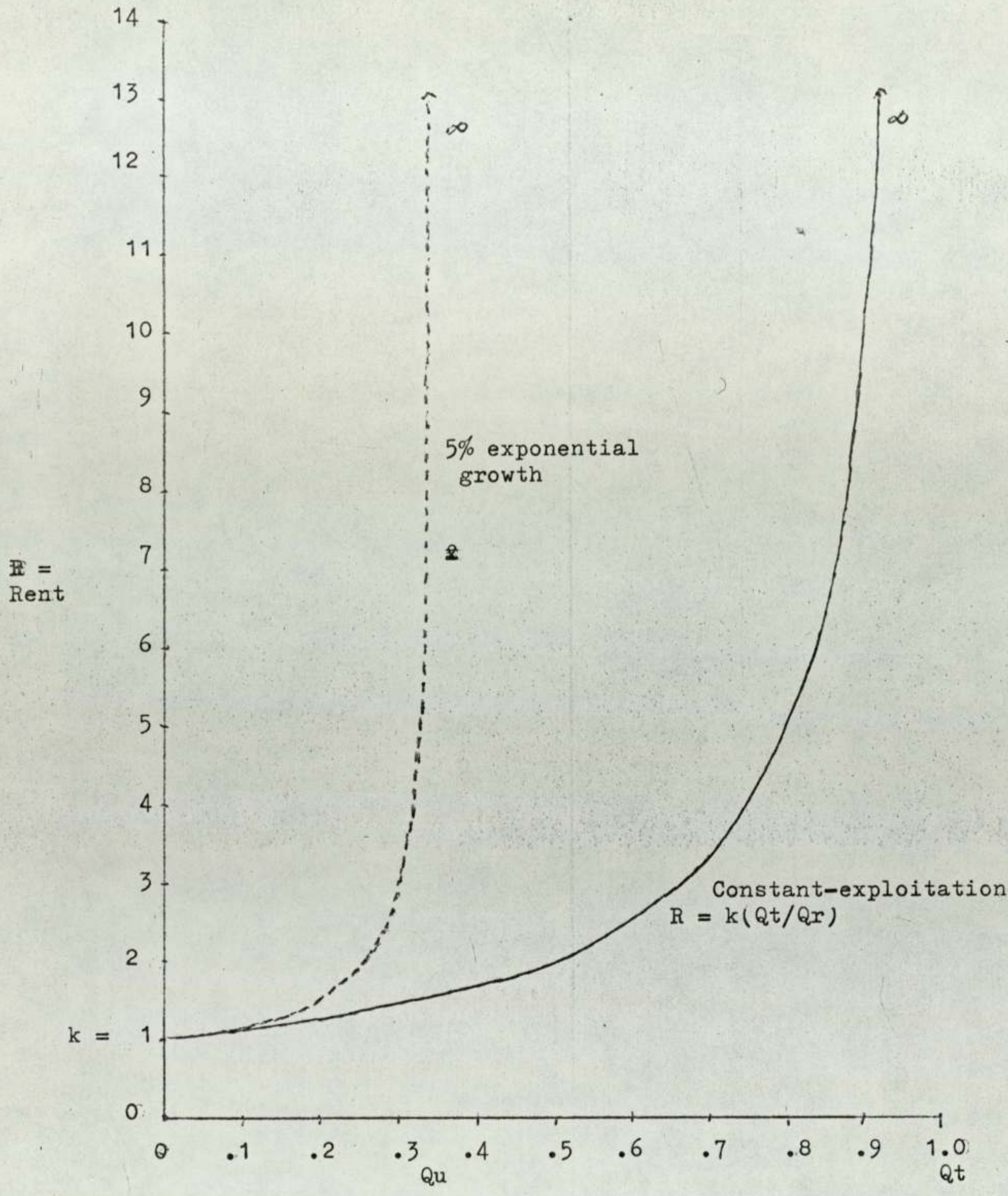


Diagram 2.1. Hyperbolic Increase in Rent with Resource Exhaustion, showing effect of exponential growth in potential exploitation rates.

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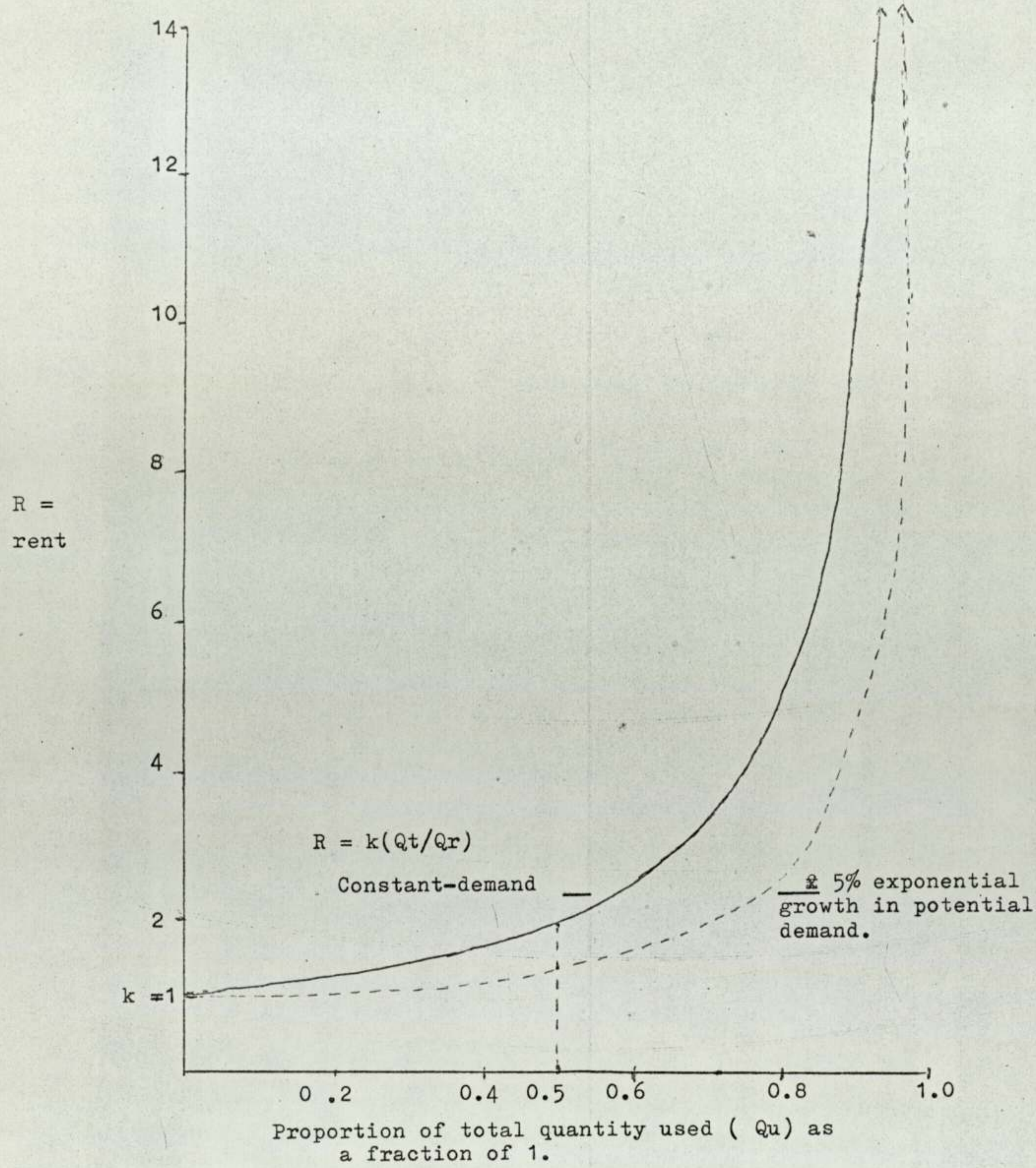

Diagram 2.2 : Alternative presentation to Diagram 2.1, showing constant-exploitation and exponential-growth curves drawn to same asymptotes. Shows effect of exponential growth in prolonging the low-rent "extravagant" phase in proportion to resource life and in sharpening the transition to the high-rent "scarcity" phase.

been extracted, the variation will be

$$R = k.Qt/Qt - Qu. \qquad \text{..... (1)}$$

at any stage of depletion of the resource, in terms of the rent at the start of exploitation. The relationship of rent to exploitation is thus hyperbolic, and it will be seen that the rent element increases very slowly during the first phases of exploitation and very rapidly during the latter phases. Witness the first differential

$$\frac{dR}{dQr} = \frac{Qt}{Qr^2} \qquad \text{..... (2)}$$

where $Qr = Qt - Qu$.

All this obtains when the rate of extraction remains constant. From the second curve on Diagram 2.1. can be deduced the effect if extraction proceeds at an exponential rate of growth, in this case 5%. If I is the rate of extraction initially, n the number of units of time involved, the amount removed at time n will be

$$Qu.n = \frac{I \left((1+i)^n - 1 \right)}{i} \qquad \text{..... (3)}$$

where i is the exponential rate of increase in extraction. Substituting in (1), we have

$$Rn = k. \frac{Qt}{Qt - (I \frac{(1+i)^n - 1}{i})} \qquad \text{..... (4)}$$

Diagram 2.2. conveys the same information as 2.1., but with the 5% curve replotted to converge on the same asymptotes as the constant-rate curve, to demonstrate the effect of the exponential on the shape of the curve. Starting with the same initial extraction rate, not only is the run-out time much shorter, (1.1.) but, owing to the greater rectangularity of the exponential-rate curve, the period of really steep marginal rent-increases commences later in the lifetime of the resource; and the evolution from a low-rent, abundant resource situation to a high-rent, scarce resource situation (at the apex of the hyperbola) will be extremely rapid. So rapid, in fact, that it could be within the lead-time required to find, and convert the relevant technology to, a substitute. In the case of a commodity whose short-term demand elasticity is low, very real disruption could result.

The 'shape' of this curve also explains why industrial economies tend to develop such profligate habits with resources; during most of the early period of exploitation the rent is low and most costs will be those of exploration and extraction. The rapidity with which the rent-curve turns upwards, coupled with the relative inflexibility of modern economies, explains how abundance can easily turn into scarcity - and the higher the economic growth-rate and expansion of demand, the greater this effect will be. The case of petroleum, recently, illustrates this factor - but it also illustrates other factors as well. As petroleum resources have become used, the rent per unit attributable to the remaining supplies has risen - but so has the concentration of the ownership of the remaining reserves.

It is mainly geographical accident that has concentrated most of the remaining reserves into Arab hands; and here, in addition to the normal increasing-monopoly effect, there is the historical circumstance that, the relative political strength of the middle-eastern States has increased vis-a-vis the West. While at the beginning of the century the Arab states were part of the decaying Ottoman empire and Iran was ruled by the equally decadent Qajars; and while, in between the wars, Iran was only gradually reviving under Reza Shah and the Arab states were ruled by Western mandates, regimes dependent on Western support or were trying to unite themselves (Saudi Arabia), at present the Arab oil producers are politically independent, nationally conscious and aware that their economic strength lies in unity (i.e. OPEC) and Iran is bidding to become the strongest economic and military power in the Middle East. In contrast, the Western consumer states are disunited politically and have been affected by guilt-feelings about the colonial past; and the Middle East has also benefitted by the fact that Western and Soviet power have tended to cancel each other out. While the strengthening of their position has been helped by the run-down of oil production in the continental U.S.A.: this digression illustrates the limitations of pure economics when discussing these questions.

Discussion of other rising costs with exhaustion of resources has been omitted, in order to keep the argument clear. In most cases, the increasing cost of exploration, capitalised over the lifetime of the deposits discovered and the increasing capital and labour cost of working progressively leaner ores or thinner seams and of refining from poorer quality deposits will add to cost, along with rent and will give an extra impetus to rising prices, but not with the same force as increasing rent. In a minority of cases, too, the resource may be homogenous in quality and accessibility right through the extent of its reserves (e.g. mercury). In this case, working costs will tend to be the same in real terms, disregarding technological advance, right through exploitation.

The position is less clear-cut with other commodities;

there is less monopoly power or political unity among the producers; in many cases the largest producers are themselves industrialised. Moreover, substitution is possible - and in non-energy commodites, one of the substitutes will be recycled material as against virgin. However, especially in the class of materials being considered here, the technology of re-use may have to be developed; there will be a lead-time for both this and its general adoption. The importance of anticipatory investment will be discussed later.

Self-renewing Resources.

Here, the position is, perhaps, a little less clear-cut than with non-renewables; and the assumption must be made here that the owner of the resource had complete enough control to optimize production over time.

We will make the initial assumption that the maximum continuous production of a certain biological commodity is Qm; in the case of an annual crop, this will be reached when the maximum suitable area of the crop. dictated by biological considerations - climate, soil conditions, needs for rotation - is cultivated. For the moment, year to year fluctuations will be disregarded.

In the case of a forest, fishery or game preserve, or grassland used for rearing stock, this is the maximum rate of production which will not damage the productive ability of the resource. For the moment, we will examine the short-run case and assume that this maximum production is not amenable to technical improvement (i.e. inputs of 'mental capital).

In this case, the rent position is much as Ricardo described it, assuming that demand is relatively inelastic and is determined exogenously both by cultural and (in the

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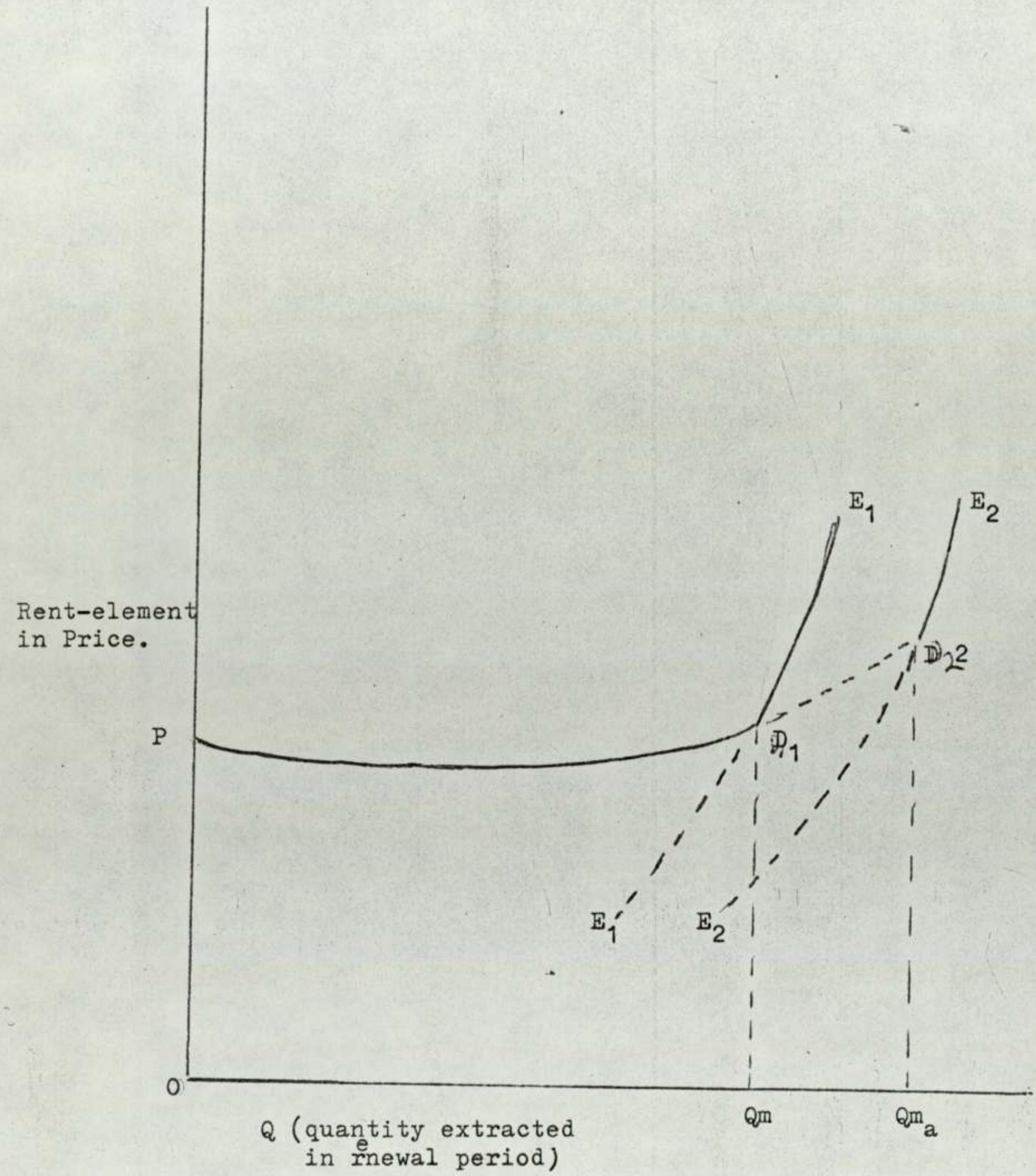


Diagram 2.3. Behaviour of the Rent Factor in the Price of Renewable Resources with Exponentially Increasing Demand over Time

case of a food crop) by nutritional considerations. Assuming that original production was below the level Qm, if demand should rise, the price will rise relatively gradually and so will the rent of suitable land. Until the level Qm is reached, land can be converted from other uses; but when Qm is exceeded, price - and therefore rent - will increase as the ratio of expanding demand to a fixed supply; which, as will be seen from Diagram 2.3. is that much faster.

Now if we drop the assumption that Qm is not amenable to inputs of labour, fixed-capital and know-how, it is possible that over a long term an intensive increase in production can be achieved; but eventually the level Qm_a, or the absolute maximum continuous production level will be reached. In both cases the same discontinuous curve results.

Of course, the real position is not that simple. Qm may be lowered by the taking of suitable land for other purposes - arable land for urban use, forest and pasture for arable etc., - which produce a higher 'yield' per unit of land. There may also be various restrictions on use of land and no market in land or its products is ever 'perfect'. However, this over-simplified model shows the principle.

If demand is increasing over time, rents and prices will tend to increase moderately up to the Qm point and steeply thereafter. There may be exceptions; high discount rates may induce forest owners to crop at above the Qm rate in order to realize a short-term gain, followed by a longer term with little or no production. Temporary emergencies may affect production policies. Again, this does not affect the basic principle.

Discontinuities.

Therefore, in both the case of the non-renewable resource and the renewable resource the rent factor, rather than 'absolute' shortage, creates a discontinuity in time. In the case of commonly-held resource with no property rights a greater discontinuity will occur when the resource gives out.

At this point, the economy ceases, as far as the commodity in question is concerned, to be resource-extensive, high-growth and profligate with the material and will evolve, if not too many dislocations are involved, to become a resource-intensive, material-conservative economy, depending for its growth on the accumulation of technical know-how. When this point is reached for several commodities and the scope for substitution becomes narrowed, the whole economy is forced into this transition. For reasons examined above, however, this point may be reached and passed before the economy can adjust; the social and political consequences of the resulting dislocation could be severe. To avoid this, it is necessary that the economy be provided with anticipatory mechanisms to enable it to react to changes.

Anticipating Scarcity.

Since the economy can only readily handle information presented in money-value terms, the problem here is to equip the economy with anticipatory mechanisms that present information in value terms.

As we have seen, rent has value as a factor in conserving scarce resources, but by itself is imperfect. Its relative ineffectiveness during the early exploitative phase renders it of doubtful value in controlling late-phase scarcities.

The market mechanism is also ineffective. 'Spot' prices are entirely determined by short-term and immediate considerations; speculative and psychological considerations as well as those of supply and demand. So are short-term forward rates. The problem is to create a really long-term forward rate at current prices - a "twenty-year (or more) forward rate", which includes possible rent changes for resources.

The difficulty in the way of establishing a real 'twenty year forward' quotation in commodity markets is, would entrepreneurs be willing to take risks on a twenty-year rate? (An indexation procedure could be used to counteract inflation). Many businesses tend to operate on a day-to-day or very short-term basis, but would the wide range of probabilities on a twenty-year view preclude trading as far ahead? One answer is, that the forward rate need not be an actual trading price, but a notional one for planning purposes only. Can we then establish this notional price?

This could be quite possible, especially if substitution technology was ignored in the reckoning; after all, substitution technology is one of the hoped-for results of this exercise. The purpose of the twenty-year market is, after all, to enable vendors of raw material to judge how much material to hold off the present market and therefore raise present prices and encourage greater economy in use.

Another possible approach is to estimate the 'twenty-year forward' price and then narrow the difference by levying an ad quantitatem tax. This would have the advantage that prices would be raised during the early 'profligate' period far more, in proportion than during the 'late' period, thus encouraging thrift and substitution. Taxation may, to some extent, be open to the traditional classical criticism of attempting to influence the proportionate inputs of land, labour or capital into any activity by means of taxation, or to the classical argument against attempting to reinforce the action of the market by means of taxation (7); however, it should be remembered that the classicists were describing short-run effects, not situations separated by long periods of time. By observation, ad quantitatem taxes would seem to work in the early stages. Contrast the long-continuing fuel scarcities suffered by American motorists from the winter of 1973 to the present with the relatively short period of scarcity suffered as a result of Arab political activity from October 1973 to February 1974, on this side of the Atlantic. Up to 1972, some 40% of American petroleum consumption consisted of motor spirit, compared with 12-14% in OECD Europe as a whole and 16% in Britain (8); this was entirely due to the contrast between cheap, lightly-taxed gasoline in the United States and expensive, heavily-taxed petrol in Europe. The latter therefore developed a market for small, economical cars; the former, a market for extravagant (6-8 m.p.g.) large cars - the proliferation of which eliminated the public transport systems that might otherwise have provided an alternative. Therefore, when scarcities of petroleum developed, Europe was proportionately less affected.

Economic temporal myopia may not always be caused by market deficiencies. In a footnote, Kneese, d'Arge and Kokigu (9) have described the situation as regards discount rates, as used in discounts of future investment, as "explosive"; not an overstatement. Current interest rates, the reciprocals of which are used for discounting, may at any time be too low or too high; at the present time, distorted as they are by inflation, they are almost certainly too high. At 15%, the present-value of £1 in ten years is just under 25p., for one example; really high discount rates discourage long-term investment and resource-planning and would make impossible any long-term forward pricing. All economic activity is distorted towards the short term. On the other hand, zero-discounting is not realistic; the value of costs and benefits accruing in the future is logically lower than at present. However, the equation that should decide how much lower that value will be is not $1/(1 + i)^n$, where the symbols keep their conventional accountancy meaning. Any discount of the future should be in proportion to the degree to which the future is unknowable and this depends on the probabilities of expected events, or combinations of expected events, occurring. This would indicate a theory of discount rates based on Poisson probabilities, the working-out of which is beyond the scope of this work. These probabilities will depend on a proper system of forecasting being established; and even then, many values may still have to be subjective. Inflation, of course, will have to be controlled and, if possible, eliminated. Even with the provision of constant price indices, because of periodic alterations to weighting it becomes difficult over long periods to maintain a constant index of values.

The final obstacle to the market's re-adjustment to changed circumstances is the presence of ingrained attitudes. This being an interdisciplinary thesis, it is reasonable to leave the realm of economics temporarily, for this part of the discussion. In all societies and throughout history, responses to events - and the shaping of endogenous events - have been made neither by the 'mass movements' nor the 'forces' so beloved of neo-Marxists nor by individuals - the 'great men' so beloved of the 'Fuehrerprinzip' school of history, but by various minority-groups within society - different minorities playing different parts at different times. Some are in greater positions of power than others and some are quicker at adapting than others. In our case, we find that the minorities that make up political parties still tend to assume indefinite growth in their political philosophies and policy-making assumptions. Many industrial managements and influential popular journals such as the 'Economist' tend to assume the same assumptions. If these minorities still persist in their assumptions, dislocations may occur; political, military and business history is littered with disasters that occurred because the influential minorites concerned read the signs and disregarded them, because the message did not fit their own preconceptions.

Materials, Pollution and Recycling.

In this section we turn to the relation between waste accumulation, pollution and recycling.

Waste accumulation and pollution have never been, and will never be, as powerful determinants of recycling as the relative scarcit of the primary material or the rent-element in its price. This is, firstly, that any waste-generator desiring to reduce waste production and accumulation has a choice between a 'hygienic' method of disposal of his waste and recycling and the decision will be taken on the basis of the lower of the two net present costs; and secondly, there is the essential property of 'negative spillovers' from waste generation that they do not, largely, fall on the producer, except insofar as they affect himself, his own plant, and his employees, but on society at large and on the general public. Hence the term 'spillover', or 'externality'. Assuming the classical motivation of entrepreneurs to maximize profits - and therefore minimize internal costs - there will be no incentive for the generator to 'internalize' the costs by treating his wastes by whatever means, to minimize their impact, rather than simply discharge them 'over the fence'. For negative externalities to be internalized, society has to impose them on the generator - and that means government action.

Now, before government action can be taken, the nature of the negative externality produced by the waste in question has to be known. There can be a very long time-lapse; consider the length of time that elapsed before the negative-spillovers from accumulations of human excreta in towns became known, as mentioned on Page 15 above; all too often, negative externalities are identified the 'hard way'. After identification, the next process is usually alerting the government to the problem and securing the requisite legislation. This process, at least in democracies, is usually accompanied by political argument on both sides, creating more time lapse.

Quantification of negative externalities is a complex task. If the strategy to be used is a complete prohibition on discharge - if, say, the costs imposed even by a small discharge are too large to be catered for any other way, or where dangers to human life are involved (the costs of human life are usually taken in Western society to be absolute), there may be no need for quantification; but where some form of 'pollution charge' is contemplated, quantification is needed. Some of the costs are intangible - damage to health may not only decrease a person's productivity (estimable), but may adversely affect his family life (less estimable), and the contribution he may make to the community outside his formal occupation. Some pollutants and wastes cause mainly 'aesthetic' pollution - they are ugly and degrade the environment by their visual impact. Others attract pathogens, as do many of the wastes dealt with in this thesis; others (see the chapter on agrarian waste, below) while not especially toxic themselves, have deleterious effects on water-courses, with significant economic effects, some of which are concerned with recreational use. The process is complicated by the cumulative effects of some pollutants, whose action takes place over periods of years, making detection and quantification all the more difficult.

Having detected, quantified and charged the generator for the impact of his waste, he has three strategies available -

(a) to recycle the waste,

(b) to install a process to dispose of the waste hygenically, or

(c) to examine his production process with a view to modifying it in order to minimize or eliminate discharges of waste.

The latter is especially applicable where substances of value are discharged as waste or the arising are too irregular and seasonal for recylcing or permanent disposal installations to be appropriate, as with silage waste liquor. The choice of strategy will be dictated by cost; and this question of strategies will be enlarged upon in the next chapter.

Therefore it will be seen that rising raw-materials costs will probably be of greater influence in the choice of re-cycling than increasing internalised costs of waste-generation and pollution and both factors will tend to reinforce each other.

Rising Costs - Raw Material and Disposal Cost.

As an example of long-term rising materials cost, much of the material that we shall be dealing with, especially the 50% paper content of town refuse, has its primary origins in timber. Timber is the only constructional material whose real price has consistently risen during this century and the upward trend will be reinforced (10). Paper prices have risen very steeply recently (11), and there are still scarcities of pulp, etc. Part of the reason for this has been the very large investment that paper mills have been forced to make in pollution control; part has been for short run reasons such as labour, disputes in Canada; part due to general inflation. This is not so much due to increasing absolute scarcities of timber as to increasing demand and to increasing rent-elements. There are still areas of unexploited forest in the world, especially in Latin America and the U.S.S.R.

Disposal costs are also tending to rise as societies and governments demand higher disposal standards, especially for hazardous wastes and the same hyperbolic tendencies act on the rent of property rights over tipping-sites - and the same tipping sites grow ever scarcer. These costs will be dealt with in the relevant sections. This combination of rising disposal costs and materials prices will encourage the investigation of recycling and re-using many products in common use, including many of those that we will be dealing with.

Importance of Timing.

For many products, rising primary prices and disposal costs will make recylcing an imperative - but when? In the next chapter, timing will be discussed; it is very important from the point of view of the investor and will be different for each product. In some cases the question arises immediately, in others in the immediate future.

In order that viable recycling schemes be installed, the necessary installation and development lead times must be taken into account so that installation may be made in time to prevent or minimize dislocation through sudden shortage; but installation must not be premature - unnecessary losses through high-cost production could be incurred. This will also be dealt with in the following chapter.

References.

(1,p.29) See Marshall Sahline, "The Original Affluent Society", "The Ecologist", v.4(5), June 1974. Introduces the idea of the cultural determination of wants by examining the low level of wants in hunter-gatherer societies. Because of the need for mobility, the marginal utility of goods in such societies is very low.

(1,p.30) D. R. Meadows, D. L. Meadows, Jorgen Sanders, Wm. H. Behrens III, "The Limits to Growth", Earth Island Press, 1972. Must be read in conjunction with "Thinking About The Future", H. S. D. Cole, Christopher Freeman, Marie Jahoda, E. J. R. Pavitt (eds.) Pub. Chatto & Windus, for Sussex University Press, 1973.

(2) Inaugural Lecture, University of Aston, 1972.

(3) U.N. Report on Iron Ore Resources, 1969.

(4) Many States keep their true resource position secret.

(6) Press (Sunday Telegraph) Report, 1973 - interview with Chou En-lai. Treat with caution.

(7) See E. J. Mishan, "Twenty-one Popular Economic Fallacies", Pelican 1969, among others.

(8) O.E.C.D. Oil Statistics 1971. Paris, 1972.

(9) R. C. d'Arge and K. C. Kokigu, "Economic Growth and the Environment", Quarterly Review of Economics, Autumn 1972, p.64.

(10) A. J. Grayson; Paper delivered on the occasion of the 50th Anniversary of the I.Chem. E., 18.4.72. Rates of increase have averaged ½% - 2% p.a. for pulpwood, 1% - 2% p.a. for sawn wood. Prices increased of order of 300% 1973-4.

(11) According to Materials Reclamation Weekly, 14th April, 1973 there has been a considerable upsurge in the demand for waste paper, so much so that the trade is actively considering tapping domestic-waste sources for the first time. This is a contrast to the depressed state of the market in 1971, when this project started. Paper for book use increased from £175 per ton to £350 per ton in the year 1973-4; firms in the Birmingham area are offering £18 per ton for sorted newsprint in ton lots.

CHAPTER 3: MICRO-ECONOMIC ASPECTS OF RECYCLING AND DISPOSAL - UPGRADING AND TIMING.

Introduction.

Having dealt in the last chapter with the large, theoretical issues governing recycling and disposal, we will now discuss the issues arising on the micro-economic level - that of the waste-generator or disposal collector, or any firm, production unit or local authority faced with a choice between recycling or disposal of wastes. Useful institutional changes and improvements will be discussed, as well as specific issues relating to low-value organic wastes.

The Question of Recycling or Disposal.

Now that the doctrine of complete "laissez-faire" in regard to the conduct of firms towards the rest of society is no longer a live politico-economic issue, and the connection between the discharge of many wastes and environmental damage has been established and is now beginning to be quantified, society is in a position to return at least some of the cost to the polluter. The form which this may take may range from discharge charges to prohibition on the type of discharge, depending on its nature and toxicity and sanctions may range from fines for non-compliance to legal action to close down production at the offending plant. The standards to which all waste emissions will have to adhere to will have a propensity to rise, and in all cases, an input of 'mental labour' will occur, in order to develop complying systems.

As detailed on Page 54, a firm faced with a change from a zero-cost disposal "down the drain" or "over the fence" situation to a charge-on-disposal or prohibited-disposal situation has three basic strategies:

(a) to dispose of the waste by an approved hygienic method, 'hygienic' meaning with least negative spillover;

(b) recycling the waste; and

(c) re-examining the process concerned in order to minimize the generation or discharge of the waste.

In real life, combinations of any two or all three of these options may be used, depending on technical practicability and cost over the lifetime of the proposed installation.

Option (c) requires a greater input of 'mental capital' than the other two, as it requires an examination of the entire process concerned - whether of production or consumption; and is only really applicable where new investment is contemplated or old plant is approaching the end of its useful life; in the latter case it may well be that the cost of retro-fitting according to strategies (a) or (b) may be prohibitive in connection with the plant's remaining life and premature scrapping may be called for. Option (c) is also especially applicable where escapes of valuable material are taking place, that are too spasmodic to be recycled in the normal way; but it is limited by technical practicability. However, by empirical observation, much waste discharge has been reduced by changes in basic technique. The necessity of limiting discharges of dark smoke and other pollutants into the atmosphere from dwelling-houses following the passage of the Clean Air Act, 1956 and the smoke-control orders that followed not only stimulated the design of smokeless-fuel appliances but also stimulated the design of improved systems of gas and electric heating - and alerted the British consumers to the advantages of fluid fuels over solid (e.g. no ash clearance or hauling-in coal, greater cleanliness and safety) and to the benefits of central heating Discharges from the chemical industry have not risen pro rata with scale of production, owing to improved control of emissions; modern, properly installed refuse incinerators likewise have a far cleaner stack emission than early multiple-hearth models - albeit at considerable cost (see Chapter 4). The retirement of steam locomotives from the railway systems of almost all industrialised nations and from many agrarian ones as well conferred a pollution reduction as a side-benefit, since the main reason for the change to diesel and electric traction was greater operating efficiency and economy - not always realised. However, it is unquestionable that in this set of changes the welfare of people living and working alongside the railways, as well as the passengers and staff, was greatly improved by the elimination of coal-burning steam; the general welfare of the population of the larger conurbations was improved (1) and the cost of cleaning property on or near the lines, and its deterioration, was reduced. However, the opportunities for this kind of process re-examination tend to be comparatively few and random, and dependent on the availability of alternative technologies; witness the contrary case of reducing the process-wastes (i.e. exhaust fumes) of road transport and the negative spill-over therefrom. In practice we are left with options (a) or (b) - or combination strategies - in most cases.

To take a very simplified model at first, the decision as to whether to adopt recycling or a hygienic disposal process will depend on whichever has the lowest present cost. In other words, if

$$(Ir - (Cpr + Csr)) = (Cpd + Csd) \qquad .... (1)$$

where Ir is the income from recycling, "income" also including materials purchases saved, Cpr is the private cost of recycling, Csr is any remaining negative spillover from recycling, placed on the firm, and Cpd and Csd are the private and social cost of disposal by hygienic means respectively. These can all be discounted over the lifetime of the project; but the limitations of discounting have already been discussed.

However, this is much too simple. Although the private cost of recycling - Cpr - may be greater than Cpd at first, it should also be remembered that because of factors discussed in the last chapter, Ir may well tend to rise during the course of a project: in addition, the actual values of all the terms are not only governed by ordinary pricing considerations, but on technological and institutional factors as well. If it is anticipated that prices for recycled products and hence Ir will rise, technological inputs will be made to reduce Cpr; as will be shown in Chapter 4, various influences will combine to increase Cpd.

Vernon L. Smith (2) has written a far more rigorous analysis of the choice between recycling and disposal than is possible here; but his dichotomy between recycling and 'littering' is too extreme; hygienic disposal processes are those which are adopted to obviate the effects of the 'littering' of waste products at the least cost to the generator - in other words, to minimize Cpd + Csd, - whereas Smith believes them to be merely 'littering at a distance'.

For reasons given in last chapter and above, there is expected to be a 'serious' interest in recycling processes; this chapter is concerned with the firm etc. contemplating adopting them.

Upgrading in relation to Waste Reclamation.

The criterion on which the reclamation of presently low-value or valueless wastes depend is the degree to which they can be upgraded. Most organic wastes, for reasons explained in Chapter 1, cannot be recycled as they stand; they must be processed into a useful form or upgraded. Upgrading, here is any process converting a lower-value material into a higher-value one, where

$$G = Pu - Pr \qquad ..... (3)$$

where G is the gross amount of upgrading, Pu is the price per unit of the upgraded material, as expected, or the expected price of the material being substituted for, and Pr is the expected price of the raw material. Pr may be nil or negative initially; the generator of the waste may be willing to pay to have it removed; but if a market for the upgraded product develops, Pr will become positive. Pu is the price of the quantity of the upgraded material made from 1 unit of the waste; some bulk reduction is bound to take place. For preliminary investigation, the strategies of greatest interest are those that maximize G.

For a second-stage investigation, the object is to maximize

$$N = Pu - (Pr + Cpr) \qquad ..... (4)$$

where N is the net upgrading and Cpr is the private cost of recycling. Both the gross-upgrading criterion and the net-upgrading criterion, applied together, will be needed to decide on the most promising strategies.

Obstacles to Recycling.

(a) Mixing.

There is one golden rule in reclamation - do not mix wastes or allow them to become mixed. The costs of contaminating or mixing a waste vary from zero to low; the costs of un-mixing a waste can vary from high to infinite - and by infinite is meant those cases where there is no technology capable of unscrambling the components. In a two-component mixed waste, the cost of separation will rise in inverse proportion to the proportion of the smaller-volume component to the larger - and in direct proportion to the purity demanded for the extracted material, whichever one is the contaminant. In Chapter 4, municipal waste will be dealt with - a prime example of a mixed waste which has defeated many attempts at reclamation. Dilute metals waste from industry are another example.

Some wastes are generated mixed. Any among those in which we are interested, the mixed solid and liquid components of mammalian wastes are the chief examples. Even among high-value metallic wastes, however, these mixed waste arisings present the greatest challenges to reclamation technology; these are wastes arising from the discarding of unwanted machinery. Automobile scrap is, of course, the most publicised and most researched example, presenting as it does a complex and intimately interwoven bundle of materials whose separation consumes inordinate amounts of labour-time, despite the high value and scarcity of many of the materials involved; presenting as it also does a considerable "aesthetic" pollution problem and a considerable 'political' challenge to the reclamation industry by being the number one symbol, to the general public, of the profligacy of modern civilisation. There are many others, of equal complexity; copper-covered aluminium wire can not only ruin a copper melt if fed into it but can ruin the furnace lining as well; and, in our own chosen field, there are the N.E.P. (not easily pulpable) papers, bonded to plastics or (worse) bitumen-coated. Segregating plastics from paper is a difficult proposition, anyway; separating mixtures of thermosetting and thermoplastic plastics is all but impossible. However, work done at the Warren Springs Laboratory, the Battelle Institute (on cars) and other institutions on the technology of separation of substances may issue in viable processes to reduce the cost of extraction from these wastes. They are not, in any case, greater than the reduction of metal from low-grade ores.

This caveat against mixing does not apply to the predetermined combination of two or more waste materials to produce a material or materials of economic value.

(b) Institutional factors.

These exist both in the private and the public sector. In the private sector, these consist in the type of firm at present in the industry, and those institutions that could be there but are not.

In the first category, while the leading firms in the industry have evolved far beyond the "rag-and-bone man" image that they are trying to shed, most are geared to the haulage and disposal of waste rather than to recycling. It is still a somewhat fragmented industry, firm size being comparatively small and family businesses being important; entry and exit appears to be comparatively easy. A few of the larger specialist scrap-recycling firms (Proler Cohen, in north

London, and the Alfred Bird group, who originally specialised in complex plant demolition are two examples) and one or two of the disposal firms (Redland Purle as an example) are developing large-scale transport, processing, and incineration operations, but in the main the size of operation has tended to limit the technological development of the industry, especially as regards reclamation of materials. This could be remedied by the entry of firms from outside the waste industry; Tankerfreight Limited, has already announced the setting-up of 'wasteplexes' or regional industrial waste depots where wastes could be sorted or reclaimed.

However, although transport of wastes is a considerable problem in reclamation, and recent innovations designed to reduce handling costs (containers, large capacity skips, rail transport of wastes (3)) have been and will continue to be important in waste disposal and reclamation, other innovations are necessary. The first is to create some form of marketing system for wastes; at present many possible reclamations go by default because the generator of the waste concerned does not know of a possible market, and a potential consumer does not know that the waste products concerned may be useful to him, because the industries concerned have little contact with one another. This marketing system could not only encompass brokerage and price-quoting (which to some extent already occurs with non-ferrous metals) but also firms which process the wastes they are handling into semi-manufactures. The existing industry could be extended, perhaps with government encouragement, to assume these functions; also, perhaps with central help, to encourage research and development. Because the pattern of waste generation, markets, scarcities, prices and outlets is constantly changing, however, this section of the industry should be left to private industry for its normal running.

The public sector - dealing with household refuse and sewage, as well as much trade effluent - has other problems. The pre-April 1974 authorities, especially, did not attract entrepreneurial ability and with few exceptions have not desired to engage in the sale of waste products or have not been successful; the smaller authorities did not attract much executive ability either. The capital expenditure of local authorities is financed almost entirely out of loan, the exception being where capital items are purchased out of current revenue; and the timing of loans is controlled by the Ministry or Government Department concerned with the activity - currently, the Department of the Environment - via the clumsy device of the loan sanction. The length of term of loans is tied to the type of asset being procured, from 60 years for buildings etc. to 5 years for furniture and fittings, according to a five-point scale; incredibly, this standard scale was only issued in 1969. Sanctions for loans are issued by the Government according to its own view of national fiscal and economic needs at any one time rather than according to local needs, this being one means of controlling local authority spending; but the variations in government policy due to general economic instability have been so great as to deprive the local authorities of the ability to plan forward. In any case, total loan financing is unsuitable for areas where goods and services are marketed, as opposed to areas of activity where services are provided from taxation. The administrative structure, moreover, was not suited to rapid decision. The practical effect of the new structure of local government has yet to be felt; the creation of the larger first-tier authorities responsible for disposal should place more human resources at the disposal of the refuse sector, but the divorce of the responsibility for collection and disposal between the two sectors could create problems, especially where the organisation of separated collections was called for.

Furthermore, the committal of many local authorities to incineration may be a problem. Outstanding loan debt on an incinerator may be so high as to make changes that would reduce the working time of the incinerator difficult or impossible. There is also the question of 'psychological capital' invested in an existing system - that will be dealt with below.

(b) Cyclical Factors.

Consider the open-loop, mentioned in Chapter 1, and shown in Diagram 1.2b. The total quantity of material available during any period of time will be p + qv - l, where p is the input of primary material, q is the quantity of material in the loop, v is the velocity of circulation expressed in cycles per period and l is the loss of material from the cycle. The efficiency of recycling at any time can be expressed as

$$E = \frac{r}{p_{(t(0) - t(m))}} . 100 \qquad ..... (5)$$

where r is the actual amount recycled at t(0), the present time and $p_{(t(0) - t(m))}$ was the input at time t(m), before the present, t(m) being the mean time that the commodity in question spends in use. Now it is essential to understand that present recycling must be compared with past input, not present input; too many publications give as recycling efficiencies the percentage of current output derived from recycled material. If consumption of the material has altered materially since (t(o) - t(m)), this will be misleading.

The component l, being the loss from the cycle, which expressable as 100 - E as a percentage of the input at time t(m), can be divided into a technical component, l_d, being the loss determined by the technology used and an economic component, l_e, which is determined by the price of the primary input and the cost of recycling the lost material, as well as the prices for the manufactured articles. Now the costs of recycling of the materials emerging from use into the waste stream are not homogenous; those that form l_e are those whose marginal recycling costs (for reasons of transport from place of arising, contamination, etc.,) are greater than the marginal revenue of recycling. The velocity of circulation, too, is exogenously determined; the outflow of waste $w = p_{(t(o)-t(m)^{-1}d)}$ is determined by the input t(m) previousl and is inelastic, the exact degree of inelasticity depending on the length of $t_{(m)}$ and the freedom the user has to lengthen the life of the product.

Now, in the case of paper and some other wastes with which we are dealing, t(m) tends to zero; the use is of infinitely short time or immediate, as with newsprint, packaging, etc. Now should there be an exogenously-determined fall in demand for paper, due to a cyclical depression, or a fall in the price of primary input, the marginal revenue for the recycled product will fall and the component l_e will rise in volume, because the volumes of paper already consumed will continue to emerge into the waste stream. Therefore, at the onset of a depression, one sees in this case a surplus of waste falling out of the cycle.

Contrariwise, as a depression ends or a boom picks up, demand for both primary and secondary material will increase; but owing to the lack of production during the depression, there will be a shortage.

Where the waste arises from the dismantling of capital goods, a different pattern emerges. Here, the length of time t(m) is likely to be varied by the user. When demand for the user's products is moderately bouyant, with good expectations, plant will be scrapped and replaced at a time previously determined to be optimal; if demand should fall, however, replacement and re-investment may be delayed. The same consideration applies to consumer-durables; if the owner fears a reduction in income, or unemployment, he is likely to delay replacement. Therefore, in aluminium and some other metals much used in the motor industry, a paradox arises; a shortage of scrap at the onset of a depression. Later, as more marginal units or firms go out of production, and consumer-goods reach the end of their life, a surplus may occur. Again, as the economy recovers and booms, demand for scrap will rise, but there will still be a shortage because of the low level of production during the depression; and because, before old machinery can go out of production, new machinery has to be installed.

Hence, even where there is the possibility of recycling in the ordinary sense of the term, the cycle is liable to be very unstable, owing to the inelasticity of the waste supply. In the case of a high-value scrap, this matters less, since storage costs may be comparatively low, and even at the lowest point on the cycle, little reclaimable material will be driven out to waste because its reclamation cost exceeds its long-term revenue. In the case of low-value organic waste, however, because of its low value at the time, a larger proportion will be thrown out of the cycle by a fall in demand; because of low value-to-bulk ratios, they are proportionately more costly to transport and store, which adds to their 'elasticity of disposal'. Furthermore, during recessions it is very probable that many firms or trading units will cease production, and the capacity of the industry will be reduced, aggravating scarcity problems on the outset of the next boom. It would not be surprising, therefore, that many users of raw material would prefer to use primary material with a greater elasticity of supply and with greater reliability of supply, especially if it is available at a fixed price on long-term contract. However, at this time (1974) such sources of primary material are rare.

For these reasons, it would be beneficial for the reclaimer of a low-value organic waste to have another outlet besides the generating industry, even if that industry can use the waste - very often it cannot - unless the reclaimer is able to offer a very large price advantage over primary material. This alone would justify further research into the technology of recycling low-value organic wastes.

(c) Transportation and Trading.

As stated on page 65, transport of bulky, very often putrescible wastes presents cost problems. Wastes that arise in a concentrated form, such as domestic refuse (collected by the local authority into one place) and factory-generated waste are less expensive to collect than those that arise in a scattered form - such as straw, which will be dealt with in

Chapter 5; but cost of collection is a large factor in dealing with non-industrial waste.

Inter-urban or long-distance transport is also relatively expensive, despite the recently-opened possibilities of transporting refuse in containers by rail. For this reason it is desirable that any reclamation project be sited as near to the generator as possible; in some cases, on the generator's premises.

International trading sometimes causes disruptions; the slump in waste paper prices in 1970-71 was largely the combination of a general trade recession with the 'dumping' by Scandinavian paper producers of paper on the British market at prices lower than those of Scandinavian pulps, contrary to an E.F.T.A. agreement. However, devaluation, Britain's adherence to the E.E.C., and the present world shortages of pulp and paper have reversed the situation. Waste products also compete with each other - the highest-quality papers, and all papers prior to 1854, were and are produced from the pulping of linen and hamp rags. Trading, however, can expand the demand for waste products, some of which are already exported to low-labour-cost areas.

(e) Prejudice; and (f) Corporate Inertia, or Shon's Dynamic Conservatism;

can be dealt with together.

In some cases, there are good reasons for not using a recycled article. In the case of pharmacy bottles and, after an average of twenty-five trips, milk bottles, internal scratching provides a lodgement for pathogens and contaminants that rule out their use. The same applies to cullet (recycled glass) where colours have been intermixed; but there is, or was, much less well-founded prejudice against recycled products. This is very often based on status connotations of using recycled products thought 'second-grade' - witness the pejorative connotations of the word 'shoddy', actually a recycled-wool textile. This would be important if it affects the outlook of decision-makers within a firm or the customers of, say, a retail organisation. As important is the phenomenon described by Shon as "dynamic conservatism", (4), whereby the ability of a firm or organisation to innovate change or to adapt to exogenous change is impaired, or the rate of change slowed, by the organization, procedures and hierarchies within the firm, or the presence or absence of certain skills within it. Both "dynamic conservatism" and the "static conservatism" imposed by the received opinions and prejudices of key personnel in the firm (government department, section, etc.) will have different impacts on different firms; both types of conservatism may cause a firm to fail to adapt to a new circumstance in which effluent control was desirable; it may cause a firm to cease production or to expensively retro-fit existing equipment with disposal mechanisms, whereas a less-affected firm, anticipating the situation, will have installed, if not developed itself, an efficient recycling system (or re-examined its production system - see page 58 above). As in the history of political institutions and nations, the history of firms suggests that it sometimes takes the impact of a severe crisis to force change.

Limitations of Recycling.

Vernon L. Smith (2 above, 5) has discussed, using rigorous algebraic methods, the economic constraints on recycling at any point in time. Suffice it to say that no recycling process will be totally efficient, either from a technical point of view, or from an economic point of view. From the technical point of view, apart from process losses, there are substances which may be unusable, because of contamination by pathogenic organisms (swine vesicular disease, foot-and-mouth, *Salmonella* spp. for example) or biodeteriogens - (wood-boring insects, fungi, etc); others whose arising is too sporadic to establish a regular organization for its recycling; and those whose use implies complete destruction - lavatory and cigarette paper, for example.

From an economic aspect, those substances which do not give rise to significant negative spillover or are not sufficiently scarce to give sufficient benefit when recycled will never be recycled - see equation 1. Into this category will fall many solid, non-toxic, non-metallic wastes for whom hygienic disposal will be the best strategy. Many of these are eminently suitable for landfill disposal - power station ash, construction rubble, ceramic waste for example - which domestic refuse is not. There will also be many otherwise usable substances which will not be recyclable by the current processes at any time at the current prices, mainly because of transport costs. The total recycling, by non-biosphere means, of biosphere products, is neither necessary nor attainable. As pointed out in Chapter 1, it is the restoration of the balance in the existing cycle that is the global object; the immediate economic object is to minimize the negative spillover from these organic wastes - which largely arise from their decay processes - and minimize the opportunity-cost of disposing of these materials, hygienically. In the case of many of these wastes strict recycling is not possible;

're-use' in this case also covers recycling; and in all of these wastes, whether biological or other processes are used, some of the material will be used in the process.

Energy "Recycling".

As already pointed-out, energy is not recyclable. However, as has already been mentioned, schemes exist for the 'recycling' of energy by the burning or pyrolysis (gasification) of organic wastes; however, the relatively small quantities of energy contained in wastes and recoverable by pyrolysis or by direct combustion, compared with total demand for energy, indicate that wastes will never make a really significant energy source and are much more important as sources of material.

Recycling has also been mooted to conserve energy, by taking advantage of the fact that the energy-costs of extraction from wastes are less than those of extraction from primary sources. In the case of the more reactive minerals, this is certainly true; but the energy required to produce and extract biosphere products is very little more (except for transport energy) than that needed to utilise biosphere wastes; much of that energy is sunlight. The conservation of biosphere products is essentially a conservation of land, as well as material; and only a conservation of energy insofar as it conserves the incident sunlight on land. Even in the case of metallic products, a greater proportion of energy used may be saved if product lifetime is lengthened than by the use of recycling; as much may be saved by more efficient usage during manufacture. In car manufacture, some 45% of the energy may be saved by doubling the car's design life, as against 20% by using recycled material (6).

Timing.

The success of introducing a successful reclamation scheme depends on correct timing, as well as other factors.

As was explained in the last chapter, the prices of many primary products may be expected to rise steeply in the future; the fiscal and marketing measures that could be introduced to bring forward that date and so encourage the development of recycling schemes (this is independently of the price rises that have occurred during 1973-4) have already been discussed in Chapter 2.

For public-sector wastes, non-market pressures may have to be brought, owing to the lower market-sensitivity of public authorities and the unfamiliarity of their staff with marketing; financial structures may have to be changed. New public institutions may be set up to aid the local authorities and the private sector in adapting to new, complex circumstances, such as a formalised market; but such institutions should be as autonomous as possible in a free-market economy.

Summary.

In this chapter, the micro-economic aspects of recycling, as individual firms and authorities will be affected, have been discussed. This was in contrast to the last chapter, where global issues affecting recycling, such as rent-effects in the price of raw materials were explored. In this chapter, the factors governing the choice of recycling or disposal were examined; the problems confronting recycling - particularly mixing of wastes - were discussed in detail and cyclical problems examined. Finally, the ultimate limits of recycling were mentioned and timing re-introduced.

The following three chapters will illustrate these principles with the examples of household refuse, sewage and agricultural wastes respectively - especially the prime principle; do not mix wastes.

References.

(1) In 1953, steam railways contributed some 16% of all smoke pollution in Britain. See The First Report of the Committee on Environmental Pollution, Cmnd. 4585, H.M.S.O.; all this pollution was at low level and - as anyone who remembers Liverpool Street Station in London in steam days will agree - often concentrated in and around cuttings and tunnels in the busier railway centres.

(2) Vernon L. Smith, "Dynamics of Waste Accumulation", Quarterly Journal of Economics p.600-611, vol.

(3) "Refuse by Rail" , Report T.31, Local Government O.R. Unit, Manchester 1971. Rail transport of refuse has only become practicable with the advent of containers; the minute, open wagons in common use prior to 1960 were unsuitable for refuse transport.

(4) Donald Shon, "Technology and Change".

(5) Vernon L. Smith, op. cit.

CHAPTER 4: THE RECLAMATION OR DISPOSAL OF HOUSEHOLD REFUSE.

Introduction.

This chapter will discuss the economic aspects of the reclamation or disposal of those wastes generated by households and disposed of by local authorities, in the light of those principles which have been discussed in the first three chapters. Domestic refuse was originally the heart of the project; the original object was, when the author's microbiologist colleagues commenced the technical work, an investigation on behalf of Lucas Furnaces Limited of the feasibility of that firm entering the market for composting processes; it was already producing refuse incinerators. The reasons why composting was not found to be a viable process will be discussed in the course of the chapter; but since the elimination of composting came at an early stage in the research, attention was turned to wider aspects of waste recycling and disposal and the possibility of the recovery of material from separated streams of the waste, particularly from waste paper.

Refuse reclamation has been a subject of technical investigation for at least the last century; but so far, relative materials cost, labour costs, the heterogeneity of the refuse, and the poor costing of many of the schemes concerned have defeated most of the attempts made, except for exceptional circumstances such as wartime (1939-45). One of the objects of this chapter is to give indications as to what kind of scheme could succeed and under what circumstances.

Character of the Waste.

Domestic waste is very heterogenous and hence, (see Chapter 3) difficult to reclaim from; mechanical separation methods are both costly and fallible and hand-separation is not practicable in a high-wage Western economy; in addition the waste is objectionable to handle and refuse-picking demands skills that can only be learnt by experience - few people are willing to remain long at that kind of job. Most salvaging schemes and composting projects have fallen foul of this factor.

The composition of refuse has changed with the decline of solid-fuel burning in the home and the massive increase in packaging;

Table 4.1.

Changes in the Dry-Weight Composition of Refuse, 1936-80

(per cent)

	1936	1963	1967	1968	1980*
Dust & Cinder	56.98	38.83	30.95	22.89	12
Metals	4.00	8.02	8.00	8.87	9
Glass	3.36	8.56	8.10	9.11	9
Paper & Board	14.49	23.03	29.50	36.91	43
Vegetable & Putrescible	13.71	14.07	15.50	17.61	17
Rags & Textiles	1.89	2.61	2.10	2.35	3
Plastics	-	n.a.	1.15	1.12	1½

Source: Report of the Working Party on Refuse Disposal, H.M.S.O. 1970, *1980 estimated.

There are indications that this 1980 estimate has already been exceeded; in many areas paper content already exceeds 56%. The plastics component is low in weight but high in volume; and the largely organic refuse of 1968 had an average density of 1.7 cwts/cu.yd. as against an average of 4.37 cwts/cu.yd. in 1936. Mining areas may still have high-cinder refuse of 5 cwts/cu.yd. and over, but this is due to the burning of concessionary coal. This change in composition has implications for disposal methods; modern refuse is far less physically and biochemically stable and is more liable to biodegrade and compact, making it much less suitable as a landfill material. It is also more suitable for reclamation, containing as it does a higher percentage of potentially reusable material.

Quantities.

The Working Party on Refuse Disposal estimated that some 15 million tons of refuse were collected in 1968 and expected a 1980 figure of 17 million tons/annum (1). In the U.S.A., for comparison, some 6 lbs. per person as against 2 lbs. per person per day in Britain, though the American figure may also include some industrial refuse. While the Working Party, mindful of its tipping-oriented readership, was more concerned as to rising volumes than rising weights, weight is important for reclamation; markets must be measured to quantities.

Cost Trends.

It is not easy to establish cost-trends in the local authority waste-disposal sector; the quality of the data is surprisingly poor. The former Ministry of Housing and Local Government discontinued its Public Cleansing Costing Returns in 1965; even when it was published, it often appeared too long after the collection of its data to be really useful and the Prefaces of the returns contain a monotonous refrain complaining of the fewness of the authorities (around 112) who weighed their refuse as they disposed of it. However, from Table 4.2 below, it will be seen that the cost of refuse collection and disposal rose at an average rate of 8.3% in real terms:

(Facing p.80)

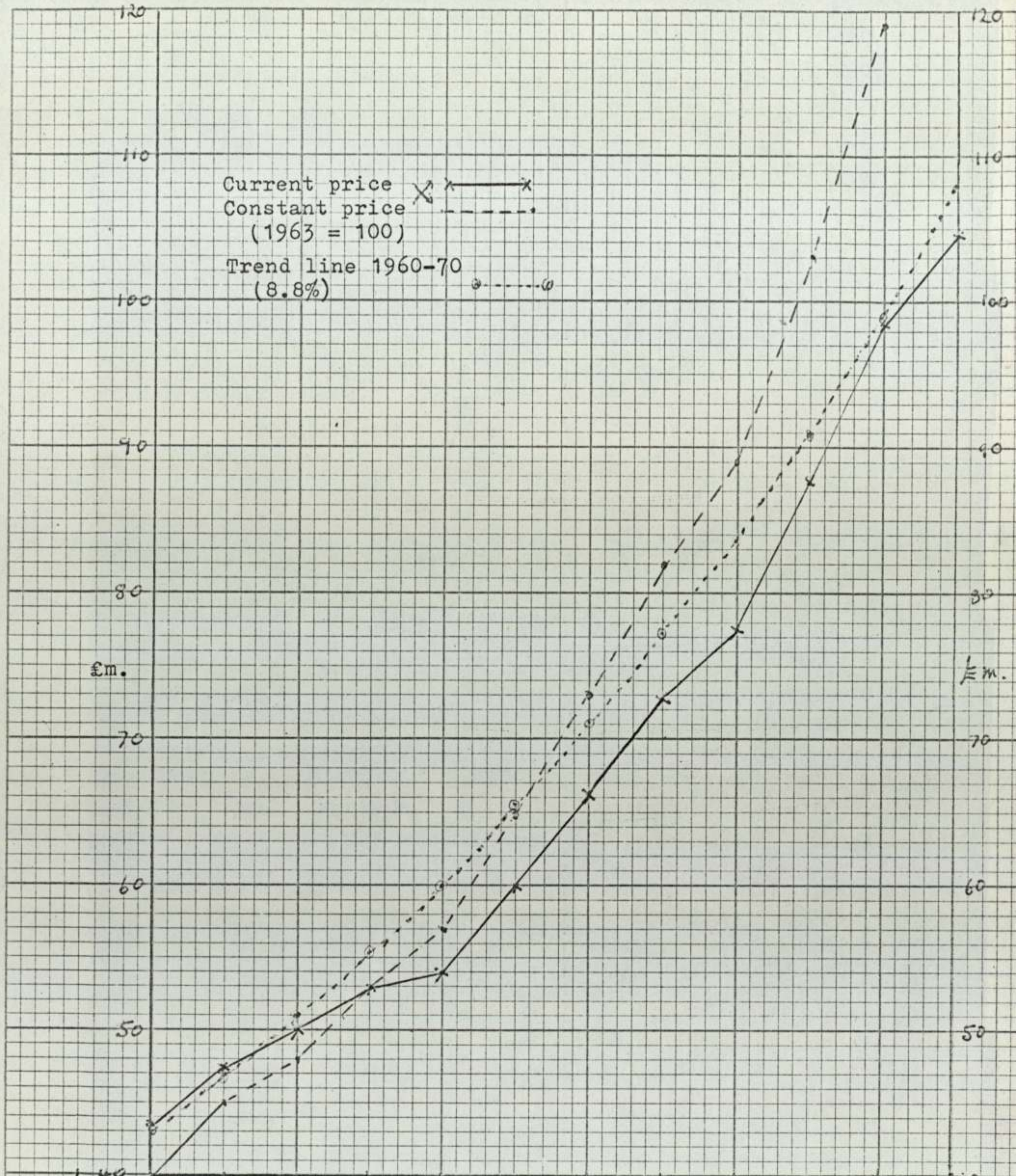


Fig. 4.1. Current Expenditure on Refuse Disposal, 1960 -71
Source: See text, Table 4.2.

Table 4.2.

Expenditure (Current) on Refuse Collection and Disposal, 1970-1.

	£m. Current price	% Increase	£m. Constant-price	%	Index
1960	40	-	43.5	-	92.9
1961	45	12.5	47.3	9.0	95.3
1962	48	6.7	50.0	5.9	96.2
1963	53	10.8	53.0	6.0	100.0
1964	57	7.6	54.0	2.0	105.7
1965	65	14.0	60.0	12.0	108.2
1966	73	13.2	66.1	10.1	110.6
1967	82	11.0	72.8	10.2	112.8
1968	89	8.6	77.4	7.0	116.6
1969	103	15.9	87.9	13.0	118.5
1970	119	15.6	98.4	12.0	121.0
1971	128	7.5	104.5	6.2	122.4
Overall		11.0 p.a.		8.3 p.a.	

Source: Central Statistical Office, "National Income and Expenditure," H.M.S.O. 1971 and 1972.

By checking against labour costs from the Public Cleansing Costing Returns, it was ascertained that effects due to wage inflation and transport costs had been eliminated by using the C.S.O. index - direct labour accounts for about 70% of the cost of refuse collection and disposal and transport for another 15%. Remaining factors would include increased costs due to vehicle expenditure, greater length of collections owing to the lower average density of urban populations, (i.e. replacement of crowded central areas by less crowded estates), smaller households, improved and more costly vehicles and the replacement of kerbside and skep collection systems with bin-carriage-to-vehicle, dustless and sack collection systems, but would also reflect the rising cost of disposal. At present, some ninety per cent of refuse is tipped; but as the nearer tipping sites are filled, transport costs to more distant sites are rising and the cost of tipping rights - either leased or bought outright - will rise in a hyperbolic fashion as detailed in Chapter 1, like other rent effects. The supply of tip-sites is complicated

(i) by the need for the tipping-site to be dry; in experiments conducted at Egham in 1954, the Ministry confirmed that the deposition of refuse in waterlogged pits or on permeable soils could cause pollution of ground water and anaerobiosis, leading to the evolution of hydrogen sulphide, ammonia, methane (under certain conditions (3)), and other objectionable gases;

(ii) the necessity of obtaining planning permission which may be withheld owing to local pressure, and

(iii) competition from private industry.

Where tip-sites are becoming scarce, near the larger conurbations, incineration has been the favoured method of disposal; but incineration is expensive (cost in 1969 - £2.50 per ton on average; at present, up to £5 per ton), owing to the high capital cost required to burn such a poor-quality fuel cleanly (see below). Capital formation in the refuse disposal sector has been rising swiftly - from £3. million in 1960 to £25 million in 1971, largely owing to the installation of incinerators, a real increase of 5½ times; although, in comparison with sewage disposal, see Chapter 5, this is still extremely small.

It is still perhaps too strong to say that refuse disposal is facing an economic crisis; despite the large absolute annual expenditure, it is still small compared with the local authority sector' expenditure as a whole. However, such cost escalations would be expected to provoke investigations into alternative methods of disposal or reclamation.

Present Methods.

(a) Tipping.

The problems facing controlled tipping as a disposal method have been extensively dealt with in the Report of the Working Party; there is no need to repeat information published elsewhere.

Crude refuse-tipping is still practised occasionally in this country, but it appears to be the dishonourable exception. No doubt badly-controlled tips also exist. Overseas, it is undeniable that even in many 'advanced' economies, standards are not so high; it is common knowledge that one of the main contributions to Los Angeles' air pollution is the complete absence of a comprehensive refuse collection system, resulting in widespread 'back-yard' incineration. Nearly all British authorities who tip use the method known as 'controlled tipping', or in American parlance 'sanitary landfill'. This involves the tipping on a prepared site (provided with drainage, an impermeable layer of material underneath if necessary, ancilliary installations such as weighbridges, workshops, lorry wheel-cleaning equipment, rest-rooms etc.) of alternative layers of refuse and earth, the whole being sealed with refuse and earth to discourage tipping.

Properly-controlled tipping need not cause excessive negative spillover; the greatest risk is perhaps of rodent or fly attraction, followed by mechanical noise from vehicles and spreaders on the tip. Pulverization of the refuse - a process that eliminates the voids in the refuse and reduces its volume by up to one-third - also renders it unattractive to rodents and flies; it is thus of most utility where tip-space is at a premium or near residential areas. At present, one of the qualities sought-for in a disposal site is its reclamation value; derelict areas such as disused quarries, railway cuttings and riverside mud flats are used. The use of land already in some kind of use is avoided.

Where land is at a premium, the reclamation of a disused quarry for, say, agricultural use, is of considerable utility; but it must be remembered that modern household refuse makes poor landfill. Shrinkage of the order of, usually, 15% will take place subsequent to tipping, owing to the biodegradation of the organic fractions and the gradual filling-up of voids. This makes the reclaimed land unsuitable for house building unless the buildings are constructed on rafts, although it will still be suitable for amenity uses where only light buildings will be constructed. In areas of extreme pressure on available land, the use of such land for specially constructed housing may be justified; Tokyo Bay is one such area; but there are much better materials that can be used as landfill - construction industry waste or ash, for example. In any case, the value per ton of refuse used, even with land sale values as high as £2,000 per acre is quite small, depending on the depth of the site; from 54p. per ton at 15 ft. average depth to 2.7p. for 100 yards depth. From the sale value at the completion of the tip will have to be deducted the purchase value of the rights to tip at replacement cost.

Tipping has remained popular up to the present because of its low cost as a disposal method, even when fairly stringent methods of control have to be used. It may well be that possible improvements in the transport of bulk refuse may extend its life, making the use of distant tip sites (up to 100 miles) economically competitive with incineration. As will be shown below, however, there may be better ways of making use of most of the constituents of town refuse, except the dust and cinder component.

(b) Incineration.

At present, this is regarded as the main alternative method of tipping when shortage or anticipated shortage of tip space has made the latter infeasible.

As a disposal method, it has sundry advantages; the ash produced is some 20% of the volume of the crude refuse, is chemically and biologically inert and makes good tip material; some systems form clinkers that have a residual value as aggregate. However, refuse is a very heterogenous fuel with an uneven composition; its calorific value varies between 2,500 and 5,000 BTU/lb and has a mean value of some 3,900 BTU/lb - wide range being caused by variation in composition and water content. This is a calorific value of 20% that of petroleum and 35% of that of coal; and owing to the presence of materials such as rubber, plastics and wet organic matter it is difficult to burn cleanly. Modern incinerators have a high capital cost and in 1969 an average cost of £2.50 per ton was estimated for the process (5); largely attributable to capital charges. Apart from those aspects of the design aimed at minimising labour costs (cranes, feeding hoppers, etc.) most of this cost can be allocated to the prevention of atmospheric pollution either from the escape of the products of combustion or from unburnt or partly-burnt refuse.

The incinerator at Castle Bromwich, Birmingham, commissioned 1968, cost £990,000; the electro-static precipitation installation alone cost £125,000. However, most of the design of modern incinerators - revolving or chain grates, fluid-bed systems, cyclone furnaces - is dictated by consideration of emission reduction; and in addition to electro-static precipitation, a typical large plant will have quenching equipment (to cool ash) and long chimney stacks - some 200-300 feet in height, to disperse those pollutants that remain. Admittedly, modern incinerators, unlike their manually-operated cell-furnace predecessors, are extremely clean in their emissions - or should be - with virtually no particulate pollution, very little sulphur (refuse contains little sulphur) and little hydrogen chloride from burning PVC; the alkaline ash tends to absorb acid gases. If the furnace temperature is maintained above 1,000 C there are no combustion problems with rubbers or plastics; the chief constituents of incinerator emissions are CO_2, water vapour and residual dust (very little). The cost, of all this is considerable.

In most modern incinerators, this cost is all-loss. Earlier installations included ash-screens at the input end and picking-belts for salvage, but this is not a viable proposition under modern conditions. In some cases, tins and other ferrous metals are recovered by magnetic screening from the ash; but the act of incineration has adverse effects upon quality. Tin cans passed through incinerators can no longer be de-tinned and are not acceptable for steel making, although they can still be used for cast iron.

The recovery of energy, either by the use of direct heat or steam raising, or electricity generating has long been advocated and practised; in between the wars, at least Glasgow and Southwark - and the Ford plant at Dagenham - used incinerator generators. Under modern conditions, however, the minimum scale of operation is 50 megawatts for an incinerator generator;

large by prewar standards but minuscule by present-day standards, where plant sizes range upwards from 3000 MW. A 50 MW generator requires an input of 10 million tons of refuse per annum, on a 24-hour day, 7-day week basis; so far, only the GLC's Edmonton plant and one plant at Nottingham (which produces both electricity and steam for district heating) have been built recently (6). Both the Working Party and the Conference on the Incineration of Municipal and Industrial Wastes (7) have agreed on these minimum size limits. An institutional handicap is that, for external use, the C.E.G.B. purchases electricity at one-quarter of its selling price to the boards; for internal use, the tariff for standby power from Board supplies would reduce the advantage. This is a contrast to the pre-nationalisation position, when many larger authorities operated electricity undertakings, and could thus credit the electricity internally at cost price to the refuse - or at least credit it with the cost of coal saved.

Direct use of heat suffers from the difficulty of finding a coincidence of supply and demand. Incinerators may have to be sited away from potential customers; and the heat or steam has to be available whenever the customer requires it. Many incinerator installations may not be worked at the same times as their customers and standby plant would eliminate any economy that a customer would gain by buying-in steam. Furthermore, even a large 16 ton-hour plant would not be economic if the interest rates were to exceed 8% (8) if used for, say district heating. Some schemes have been relatively successful - the hybrid Nottingham electricity/heat scheme, for example, and a Bristol scheme to use the heat to dry sewage sludge; but on the whole it is not of large application.

Furthermore, the poor handling characteristics of the refuse, the low calorific value and the small quantity of refuse in comparison with fossil fuel indicates that even if all of it was used for energy production, at its median value it would only supply less than 2% of national energy needs. Also, heat consumption tends to be greater in winter than in summer - but energy will still be produced, as the supply of waste is inelastic. Such surplus energy would have to be dissipated.

It will be one of our objects to show that it is the material in refuse that is important from the point of view of reclamation, not the energy.

(c) Composting.

Composting is basically an acceleration of the normal process of biodegradation of dead biosphere matter that is brought about by heaping or otherwise spatially concentrating the waste in such a way that the growth of aerobic, thermophilic, saphrophytic organisms is encouraged. The end-product is, or should be, a dark amorphous solid, showing no trace of the structure of the materials from which it has been derived. It consists largely of humus, but also contains small quantities of plant nutrient and is known as compost. Its intended use is as a soil conditioner and humus replacement.

In most systems for the composting of household refuse, municipal waste, collected in its usual mixed state, is screened to remove non-biodegradeable 'contraries' such as metals, textile fibres, ash and cinders, wood and other non-biodegradeable or not-easily-biodegradeable materials; this may involve a picking line. These rejects amount to between

30% and 50% of the weight of the refuse and have to be disposed of by other means, involving an expensive duplication of facilities. The material is then pulverised; either by a drum or hammer-mill pulveriser, or by a screw as in the Buhler process in use at Chesterfield; sometimes ammonia or sewage sludge is added to improve the poor carbon-nitrogen ratio of the refuse.

In the simplest system of all, the Netherlands VAM system, the refuse is simply windrowed and periodically turned. For the first 48 to 72 hours, the product is subjected to a thermophilic fermentation - in the Dano process, in the drum; the temperature rises to the vicinity of 48 C, sufficient to kill weed seeds and plant pathogens as well as flies' eggs. The management of the compost during this first 72 hours is crucial for its quality; this implies that a suitably qualified technician has to be available for its control. (The relative success of composting schemes in the Rhineland may be partly due to skills transferred from the wine industry - another fermentation process). The material is then left for approximately 12 weeks in windrows to stabilize and is then milled and screened for sale. Now the complexity of the process is such that costs are extremely high; on a par with incineration, at £4 - £5 per ton of compost (9). It is possible, as in the Dutch VAM process, to eliminate the initial pulverization; but since that creates rat and fly problems, this cannot be done near a built-up area. If the compost is not for sale, it will be possible to omit the final screening; but it is unnecessary to compost pulverized refuse destined for a landfill; the pulverization process itself need not be costly. Most of this cost - and the low quality of the product - may be attributable to the use of normal mixed refuse; if only separately-collected vegetable and putrescible refuse was composed, costs would be much lower, and as will be seen below, quality would be improved, and quantities would be made more manageable.

It is undeniable (10) that many composting systems have been over-engineered, which accounts for the high cost. Alterations to sewerage systems (as at Chesterfield) to bring sewage liquor into the plant has also proved costly.

The greatest objections, however, have occurred on the marketing side. With reference to Chapter 1, pp. 24-26, we have already seen that from the point of view of restoring a cyclical balance and from making the best use of recycled biosphere material, it is better to recycle the material to a point on the cycle previous to its use by man or animals; composting merely recycles the material to the humus stage; immediately prior to its return to the primary reservoir. Hence its comparatively low economic value. Compost is, esentially a source of humus, not of nitrogen, phosphorous and potash or any other nutrient; as can be seen in Table 4.3. overleaf; although humus is essential for agriculture, as will be shown in Chapter 6, there is insufficient knowledge of the functions of humus to put an economic value on it; since it is not priced, it is usually disregarded - but there are superior sources of humus nearer to the farm. The quality of refuse compost cannot be considered to be high; Purves (11) has pointed out that the heavy-metal content of refuse compost is such as to pose a contamination danger for food crops and for the same reason, the Forestry Commission has banned its use in its plantations. As can also be seen from Table 4.3., the quality also varies with time, owing to the varying composition of the raw refuse; a consistent product is impossible to achieve.

Table 4.3.

N.P.K. (%) Values of Various Municipal Composts.

	H_2O	Ash	N	P_2O_5	K_2O	Humus
Chesterfield R.D.C.	34	43.5*	0.62	0.63	0.05	22.5
Dorking & Horley (1)	7.5	-	0.82	0.21	0.32	-
R.D.C. ≬ (2)	"	-	0.80	0.28	0.36	-
Dumfries C.C. **	-	-	1.00	0.5	0.3	-
Leatherhead U.D.C. ≁ (1)	30.3	-	0.85	0.59	0.22	-
" " ≠ (2)	30.0	-	1.45	0.5	0.4	-
Leicester C.B.	35	-	1.14	0.88	0.28	-

Sources: Authorities concerned.

Symbols: * Mining area; ash adds useful trace elements;
≬ Two grades;
** One plant uses vegetation only;
≁ May 1965;
≠ October 1971.

There is also the problem of glass and plastic; glass splinters pose a handling hazard, plastics will not biodegrade, look unsightly and clutter the soil. Management also helps; the best analyses in the table above also have the most dedicated managements, and the best sales efforts; but some are poor.

With the low analyses are joined high application rates; from 3 tons/acre for Leicester to 7 tons/acre for Cowdenbeath and in one case, 40 tons/acre (11). Farmers therefore show little interest; the market consists of amateur gardeners (80%), horticulturalists, nurserymen, sports grounds, parks (including the authorities' own) and housing estates, where there are few other sources of organic material. Demand elasticity for the product is around 0.8; the market is very small. The smaller authorities such as Dumfriesshire and Leatherhead can sell all available compost, but larger authorities such as Edinburgh (population 465,421), Bristol (population 427,430), and Dumbarton C.C. (population 227,635) have had to abandon composting; Edimburgh after a particularly instructive experience. A 35 ton/day pilot plant failed to satisfy demand for the compost. A 400 ton/day plant swamped the market (12, 13). The smaller authorities still composting find the same effect:

Table 4.4.

	Population 1969 '000s.	Sales (tons)	Revenue £	Revenue/ton £.p.
Chesterfield R.D.	73.7	10 911	2129	0.19
Cowdenbeath (1970)	10.5	370	719	1.94
Dumfries C.C. (1971-2)	87.8	1 334	4850	3.67
Leicester C.B. (1970-1)	278.5	1 143	6325	3.03
" (1971-2)	"	2 633	10613	3.56
Leatherhead U.D.C. (3-year average)	39.2	1 975	6164	3.12

These, of course, are all pre-April 1974 authorities. The new first-tier authorities, having larger populations, will find composting even less appropriate to their needs.

Composting may have a minor place, for the disposal of the putrescible fraction in refuse and for making a compost or artificial soil for reclaiming waste tips. Overseas, the utility of compost has been found to be the reclamation of polders (Holland), to reduce soil losses in steeply-sloping vineyards (Rhineland), and the provision of humus for nutrient-rich but humus-poor desert sand and loess soils, (Haifa, Israel). As a general method of disposal, however, this work agrees with the Working Party that composting is not viable. There is certainly no place here for new systems.

Possible Future Systems.

(a) Pyrolysis.

This is simply the distillation of refuse at high temperatures and pressures in the absence of atmospheric oxygen, to produce a combustible gas, an ammoniacal liquor, an oily fraction, a pyroligneous/tarry fraction and a carbon char. Since the technology is based on 170 years of gas-making, at first sight it would appear surprising that schemes for pyrlysing refuse are only now being designed.

Basically, pyrolysis is seen by most of the system designers involved as a means of extracting the potential chemical energy from the refuse in a storeable and portable form, more efficiently than would be possible with conventional incineration; in other words, upgrading the fuel. (See Chapter 3). It does have attractive technical features; there is far less pollution risk, since presumably either the evolved gases or the carbon char (or an external source) would be used for heating, thus obviating the use of expensive effluent-cleaning equipment; metals could be recovered from the char in a relatively clean condition; most attractively, various hydrocarbon fuels are evolved in crude form, which could supplement increasingly-scarce petroleum sources. Overall energy recovery would be much greater - up to 15,000kJ/kg. as against a mean of 9,070 kJ/kg - or 3,900 BTU/lb with incineration (12).

As against this, the process is exceedingly capital-intensive and costly. To date, most systems have been evolved in the U.S.A., where refuse generation, at 6 lbs/person/day is three times the British average of 2 lbs/person/day. The American break-even point of, say, the process developed by the Garrett Research and Development Co. Inc., is a throughput of 2,000 U.S.tons/day - equivalent to a U.S. population of 600,000 but to a British one of 1,800,000; and owing to higher British interest rates, this size would be below a 'British' break-even point (13). Such a plant was reckoned in 1971 to cost $12 mn. (£5mn.). At that time 'oil' revenues under British conditions would have brought-in £1.83 per ton of refuse treated, as against an annual cost of £2.55. Another process developed by the U.S. Bureau of Mines, using a sodium carbonate catalyst, a temperature of 1200 C and a pressure of 4500 psig. was claimed to give a break-even point of 900 U.S. tons a day, equivalent to a British population of 900,000 - and there has been the problem of containing the molten sodium carbonate. The economics have been described as "elusive". (14, 15).

British process are also being developed. One, developed at the Warren Springs Laboratory at Stevenage, elegantly passes dried and compressed refuse through an induction coil, which heats the refuse via its metallic content. The primary objective is to recover this metal content, the 'oil' production being secondary. The British Steel Corporation is considering a scheme involving the separation of the metal from the organic refuse and setting up gasification units adjacent to obsolete blast-furnaces, which would then be used to melt the metallic content for remaking into steel. 'Oil' would also be produced, giving a gross revenue of £5 per metric tonne of refuse plus £2 per tonne of metal content, giving a total gross revenue of £7 per tonne (£7.85 per imperial ton) (16). Although this scheme has the great merit of using plant obsolete for its original purpose and therefore has comparatively low capital costs - and would have a positive spillover as far as employment in certain areas was concerned - there are logistic difficulties. Obsolete steel plants are not evenly distributed over the country, for example; and inputs of 5-9000 tons per day are called for. Now it is possible that the above revenue would support the opportunity costs of transporting refuse long distances to the plant; but Davies, who has reported the project, wrongly assumes a zero opportunity cost and also uses rather primitive extrapolations to justify estimates of probable inputs of refuse in the future. However, such a project is still worth investigating.

There are other points that have to be taken into consideration. Firstly, the products are often inferior to their natural or coal-based counterparts; the gas has a calorific value of 350 BTU/cu.ft. or two-thirds that of town gas, the 'oil' has a c.v. of 12,000 BTU/lb and is low in sulphur - and would require refining - and the char has a c.v. of 13,000 BTU/lb. The 'oil' is not equivalent to crude, but to two-thirds the equivalent volume of crude; and is largely composed of pyroligneous material. Secondly, the quantity of 'oil' produced is 50% of the nation's refuse was used would not account for more than 7-9% of current petroleum consumption; a marginal contribution, but significantly the same proportion as that of petroleum going to non-fuel uses (10). This further illustrates the fact that refuse is a better source of <u>material</u> than <u>energy</u>.

Pyrolysis is worthy of consideration, however; despite its high capital cost, it is perhaps the only method capable of reclaiming anything significant from normal mixed refuse. It would be especially useful for industrial and consumption goods where organic material is intimately combined with metals in manufacture - car bodies and seats, interior-sprung furniture, rubber tyres, used oil filters, plastic and rubber goods - where burning is liable to create a nuisance.

(b) Separated Collections.

During the 1939-45 War, many local authorities operated salvage schemes and before the reorganisation of local government, Birmingham still referred to its collection department as a "Salvage Department". However, high labour costs and low peacetime prices for waste paper discouraged most local authorities.

Worthing County Borough (17), however, has shown that separated collections are feasible. Faced with a shortage of tip space, this authority first operated the scheme in 1956. Not all the fractions of refuse can be reclaimed; vegetable material is composed prior to tipping in a Dano plant (the council does not sell direct and sales were not anticipated, but outside contractors have expressed interest), and glass cannot be reclaimed as there is no outlet for cullet (scrap glass) within an economic distance of Worthing. However, as the population served has risen, the tonnage collected has risen from 16,021 in 1955-6, when income was £23,635 (£1.41 per ton) to 27,505 in 1968-9, when income was £43,688 (£1.85 per ton). However, results have varied from a surplus over disposal costs of 24p/ton in 1957-8 (converted from £.s.d.) to a deficit of 19p per ton in the recession year of 1968-9; which shows the importance of steady markets; real income fell by 4p per ton during that period. However, the economic position in 1974 is very different from that of 1969.

As can be seen from Table 4.5, the costs of a separated collection are bound to be higher than that of a mixed one, but they do not appear to be excessively high; the opportunity cost of a collection is the difference between it and a mixed collection. Unfortunately, the low standard of cost control of the majority of authorities and the fact that only 110 others weighed theirs makes a comparison difficult. Worthing's cost controls are efficient, as they must be for any operation of this character.

Table 4.4.

Comparison of Gross Collection Costs, Worthing C.B. and 110 Authorities

Year to 31/3/last date	Mean of 110 Authorities £.p./ton.	Worthing Costs £.p./ton.	Worthing Excess %
1955-56	1.92	2.42	26
1956-57	2.06	2.64	28
1957-58	2.17	2.75	27
1958-59	2.22	2.67	20
1959-60	2.28	2.78	22
1960-61	2.41	2.97	23
1961-62	2.72	3.25	20
1962-63	2.89	3.60	24
1963-64	2.97	3.38	14
1964-65	3.03	3.42	13
1965-66	3.75	3.65	- 5

Sources: Ministry of Housing & Local Government Public Cleansing Costing Returns 1955-66 and Worthing Corporation (V. M. Gosling, A.M.Inst. P.C.)

The last figure may be indicative of poor cost control, by the other authorities, but the diminishing excess is significant.

There are limitations to householder separation. Some categories of waste do not warrant separation, by reason of small quantity; and there is a limit to the number of containers that a householder can be expected to maintain. Worthing's installation retains a picking belt, though the segregation of vegetable and putrescible waste renders the remaining refuse less objectionable to handle. The greatest difficulty would be the education of the public and the securing of its co-operation. Worthing may have an advantage - a settled population, largely consisting of retired people, with time to segregate their refuse and a sense of civic pride; no doubt appreciative of the comparative ease of handling for an elderly person separated refuse has. The opposite extreme may be found in ghetto areas, or on municipal estates with high rise flats (with only one refuse chute) and low morale and civic consciousness, where both parents of a family may be working. However, indications are that separated collections are practicable, and at low opportunity costs; Worthing's alternative in 1956 would have been a £2-£3.00 per ton incineration plant.

Markets for Reclamation.

Pre-segragation of refuse has the advantage that the component streams may be marketed to the private sector or elsewhere for further processing, perhaps united with single-stream wastes from industry.

It is not here suggested that the entire refuse-collection sector be turned over to the private sector. Not only are political factors likely to be against it; Subha Shenoy (19) and other commentators in favour of a move to a system whereby the householder contracts with a removal firm for the removal of his own refuse (and is offered a choice of removal firms) forget that:

(a) the record of private waste-collecting firms in the town waste sector has not been good, either in regard to cost or standards - vide Auckland, N.Z.

(b) that this may be due to insufficient returns in the sector for capitalism to operate efficiently; and

(c) that given the low returns and the need for some form of standards control, the situation can be no more than oligopolistic.

The private sector of the waste industry has so far not shown itself much superior to the public sector in innovation. However, there is no reason why the waste-processing industry as a whole should not process - and find new uses for - these wastes.

Dealing with each component of town refuse in order of importance;

(a) Paper.

As stated above, (p.78) paper is now the largest constituent of refuse by dry weight and is by far the largest unused component of the waste, of potential importance.

An NEDC report on the paper industry 1970 (20) stated that domestic refuse was the largest remaining untapped source of waste paper; this has been due, entirely, to the excessively high cost of collecting from door to door and duplicating the local authorities' facilities. If all available paper was recycled, some 60% of paper requirements could be met (21), saving an equivalent amount of pulp.

However, the waste-paper industry has had more than its share of the kind of cyclical instability described in Chapter 3. At the onset of a general recession, the problem can be compounded by an increased flow of ledger-paper onto the market from failed firms; in addition, during the recession of 1969-70 the problem was exacerbated by the dumping of paper from Scandinavia on the British market (22) in defiance of Article 15 of the EFTA Treaty. During that period, some 300,000 tons/annum capacity in the paper industry was lost (23). Additionally, stringent anti-pollution requirements have meant that in the

U.S.A. in particular, some 19% of capital investment has had to be devoted to effluent control in an industry where profit margins are not large; although in the American situation, this was in large part the price paid for past neglect (24). When this project commenced, therefore, there was a hugh surplus of waste paper. At the present time, owing to the rise in industrial activity since then, Britain's adhesion to the E.E.C., the depreciation of sterling, and a world shortage of paper and pulp exacerbated by the effect of the above-mentioned investment in pollution controls (as well as labour disputes in the Canadian industry), there is a shortage of paper and a high demand for waste paper. Prices for paper of paperback-book grade have risen from £150 per ton to £350 per ton over the year 1973-4; newsprint, collected by charities in the Birmingham area, is fetching £18 per ton. There is no guarantee, however, against a return to a recession situation.

The waste-paper industry is not large in toto; the average labour-force is about 4,000. It is labour-intensive, as paper has to be graded (from 1 - best white paper - to 32 - general mixed waste for board-making) and 'pernicious contraries', notable bitumen-covered paper and plastics have to be removed, as do foreign object such as string, staples, baling wire, pins etc. The kind of labour is a kind difficult to recruit in advanced economies at the present time; waste-paper sorting requires experience, and people of that degree of semi-skill are difficult to hold for long enough periods to acquire the skill. However, the industry is now very interested in waste paper from the municipal sector.

Alternative uses will still be needed, particularly for the less marketable grades of paper. Because of the short-run

uses of the primary stream and the quantities involved, a consumption product would be more ideal than a capital good, owing to greater stability of demand. The likely demand for the product and the process scale economy would have to be tailored to the size of the waste stream - the market should not be so small that it becomes saturated or so large that the product is marginal; neither should scale economies of production from other, less inelastic, sources be such as to rule out production on all but the largest scale.
Porteous' (25) scheme for the fermentation of ethanol from waste may fall into the latter category; the scale of ethanol production is so large that a scheme based on waste would not realise the scale-economies demanded; and as can be seen from pages 91-95 above, this also applies to energy.

The project at the University of Aston Biodeterioration Information Centre has been concerned with the biodegradation - or rather bio-regradation - of the material by thermophilic fungi to produce protein supplement for animal feed. Foodstuffs, of course, fall into at least two of the ideal categories. Two organisms were investigated as bio-regrading agents, here referred to as Organism A and Organism B. Organism A was used both for solid substrate fermentation experiments and tower-fermenter experiments and Organism B for tower fermentation only. Newsprint was used for the substrate; newsprint is easily available from the news-distribution system as well as from refuse and tends to arise in an uncontaminated form; newspaper ink contains no unduly toxic constituents - although this does not apply to colour supplements. The solid-substrate fermenter was simply an aluminium tray with a false bottom of perforated stainless steel, in which was placed the substrate - newsprint pasteurized at 100 C for 24 hours, having been ground down to a fibrous mass, inoculated with a heavy starting inoculum of Organism A and incubated at 48 C. After 6 days, a concentration of 6.5% protein, ascertained by a Kjeldall process, was obtained. Barnes et al. 1972 (25)). Of the various parameters involved, only the water content was optimized at 3½ times the weight of substrate; nutrient mix, temperature, atmospheric humidity, inoculation density, aeration and pH still have to be investigated. In the tower-fermenter (Barnes and Eggins, 1972 (26)) the mechanics of submerged fermentation are better understood; Organism A yielded 20% protein after 11 hours, and Organism B yielded 21.5% protein after 24 hours. However, the advantages of a superficially better result in the case of the tower fermenters are offset by the cheapness of construction of the tray fermenter, the need for an agitation system (e.g. sparging by medium or gases) and for complete sterility in the tower fermenter (the tray fermenter need not be sterile); and, when optimal conditions in solid-substrate fermenters are better understood, output from that method may be improved.

Economically, the system is as yet difficult to assess. Like most microbiological proteins, the product tends to be deficient in methionine; and, for financial, quantity and other reasons, it was impossible to conduct feeding trials on ruminants. It had already been shown elsewhere (27) that cattle were capable of metabolizing newsprint, untreated, in quantities up to 10% of normal diet; however, the mice used proved unable to metabolize either the biodegraded newsprint or the raw newsprint (Barnes, Ph.D thesis, 1973). However, if a sound product can be produced, it will substitute for soya-bean meal, currently priced at £120 per ton, having averaged £80 per ton over two years; and owing to the current (1974) Mid-West drought, liable to rise further in price. The process will also have direct relevance to the biodegradation of softwood wastes, which closely resemble woodpulp papers in their lignin content and resistance to biodegradation.

(b) Vegetable and Putrescible.

Kitchen waste is the component that renders mixed refuse so objectionable to handle. It may be difficult to find a use for this waste; the introduction of swine vesicular disease into this country, the provisions of the Waste Food Order, 1973, that waste food for feeding to pigs must be cooked for one hour in an approved vessel at 100 C, further provisions that swill-fed pigs must not be marketed except for slaughter all combine to make a re-introduction of the wartime "pig-food bin" unlikely. Much of the animal-product residue will biodegrade beyond the stage of safe feeding to animals by the time it is collected; and it is liable to attract vermin unless stored in vermin-proof surroundings.

Composting is, of course, the method used by Worthing to dispose of this component - and vegetable-only composts have the advantage of being free of contraries, thus obviating the need for sorting. There may be considerable scope, however, to develop a better-controlled biological process utilising vegetable wastes from more than one source to make a higher-value product.

(c) Dust and Cinder.

Although outside our remit, the disposal of low-value inorganics must still be considered. Possible uses are as landfill, all the more stable for the absence of organic matter, or as aggregate for road-metal etc.

(d) Metals.

Can be disposed of on the scrap-metal market.

(e) Glass.

The components of glass are not very scarce, although glass needs large quantities of energy in its manufacture. In some cases, bottles and containers may be re-used; in other cases, contamination problems make this impracticable. Different coloured glasses inter-mixed are difficult to recycle. Even crushed glass is uneconomic to transport over long distances. There are other secondary uses for glass; bricks, non-skid road surfaces, reflective paint etc.

(f) Rags and Textiles.

There is already something of a secondary market in these, geographically based in the West Riding; "shoddy" has been reclaimed for over 120 years. However, rag sorting faces the same problems as paper sorting - with the addition of synthetic fibres. Separation processes have been developed. Municipal rags, however, are not likely to be of best quality, being likely to contain a proportion of used wiping rags; however, this fraction composes only 2½% of the total refuse, by weight. Synthetic fibres will be treated as plastics.

(g) Plastics and Rubber Goods.

These virtually non-biodegradeable organics constitute only 1½% of the refuse by weight, the lightness of plastics means that it constitutes more by volume - and being non-biodegradeable, it cannot be treated biologically. However, since the original raw material is petroleum, the material has a recycle value; styrene monomer, for example, now commands prices of up to

£200 per ton. The difficulty in the way of recycling plastics is the impossibility of separating different varieties - polyethylene and PVC for example. However, even mixed plastics may be reclaimed at low level by refining into a light oil.

Photo/biodegradeable plastics may not have the utility that has been claimed for them; if the used containers are landfilled or disposed of via light-proof dustbins, they will not photodegrade.

Summary and Conclusions.

It has been shown above that there is a very good case for the reclamation of the organic materials in refuse on the grounds of:

(i) the scarcity of the materials concerned;

(ii) the growing shortage of tip sites and the increasing costs of tipping;

(iii) the unsuitability of modern town refuse as a landfill; and

(iv) the high capital cost of incineration.

The most promising approaches appear to be separated collection, followed by pyrolysis. The former may have problems of public education, the latter has extremely high capital costs and is circuitous. Composting is not viable on a large scale; it produces a low-grade product with limited demand; its capital costs are high and it is unsuitable for large authorities.

Refuse has greater utility as a source of material than as energy or land, as will be seen in the following table:

Table 4.6.

Summary of Gross Added Values of Different Methods of Refuse Disposal (Net given where appropriate).

Method	App. Value/Ton (£.p.)
Controlled Tipping, land reclamation @ £2,000/acre:	
15 ft. depth	0.54
30 ft. "	0.27
90 ft. "	0.077
300 ft. "	0.027
Incineration - direct, no picking (cans retrieved from ash)	0.099
Incineration with Electricity Generation, Edmonton:	
Net of Additional Capital Cost - $7\frac{3}{4}$% Interest	0.64
" " " " " - 10% "	0.232
Pyrolysis - "oil" sales, Garrett process	gross 1.83 -2.60 (net -0.72 to +£0.05)
BSC (own figures)(guesstimate)	5.00
Composting - Small Volume Authorities	3.50
Large " "	0.19
Separated Collections, Worthing, 1969 Average Prices	
Existing Outlets, Whole Tonnage	1.52
Salvaged Tonnage	5.75
Paper	9.20+
Separated Collections, New Outlets, should be not less	30.00

Future work on refuse reclamation should include:

(a) research into separated collections, with a view to minimizing costs thereof. Minimizing of labour-time on the part of both refuse collector and householder and optimal vehicle design (e.g. should it contain glass crushers? Avoidance of trailers as used at Worthing) should be especially considered; also problems of high-rise flats.

(b) Further technological investigation of processes to utilize paper and other organic wastes, other than those described above, in the production of useful material to strengthen markets.

(c) A strengthening of the quality of the data produced by the refuse-collection sector. The diminished number of disposal authorities, and an increase in the quality of their staffs, should improve the situation.

References.

(1) Report of the Working Party on Refuse Disposal, H.M.S.O. 1970, p.20. Table C. Although 2 lbs/person/day is used as a yardstick, the reality is nearer 1.75. This is high by international standards, only exceeded by Canada, the U.S.A., and Sweden.

(2) e.g. the 1965-6 return, published in 1968.

(3) As on the GLC tip at Merstham, Surrey, where an alkaline sub-soil maintained the pH level within the limits required by methane bacteria to evolve the gas in quantities large enough to be ignited. See "Public Cleansing", May 1972, p.233.

(4) "Refuse by Rail", L.G.O.R.U. Report T.31, Manchester 1971.

(5) As used as yardstick in "Refuse by Rail", ibid. Actual costs range up to £5 per ton, depending on time of installation of system (local authority accounts are kept on a historical-cost basis), cost of site, cost of system and intensity of plant use.

(6) Edmonton statistics; Appendix J of Working Party, p. 162.

(7) Conference on the Incineration of Municipal and Industrial Waste, paper 7.

(8) Ibid.

(9) Working Party, Ch. 7, pp.52, 53. The Working Party's pessimistic view of composting was very much influenced by the experiences of Mr. J. Scott in Edimburgh; a conclusion shared by this section.

(10) Particularly the Dano, Dano-Buhler and "ventilated-cell" processes. See George J. Kupchek, "Economics of Composting Municipal Refuse in Europe and Israel with Special Reference to Possibilities in U.S.A." American Public Health Assn. 1971. Chesterfield's sewage diversions accounted for annual capital costs of £2,000 out of £16,000.

(11) D. Purves, "Environmental Pollution", Vol. 3(1), p.17ff.

(12) Taken from authorities' own figures and L. P. Brunt, "The Engineering and Economics of Composting Plant", in Paul Wix(ed.) "Town Refuse Put to Use", Cleaver Hulme Press, 1961.

(14) U.S. Bureau of Mines' own supplied information.

(15) "Agricultural Engineering", Vol. 53(3), March 1972. pp. 17-19. But see De Forest "The Oil Conversion Process; an Assessment", same publication, p.20. He describes the economics as 'elusive'.

(16) Norman Davies, "Recycling Refuse; New Life for Old Ironworks", New Scientist, V.62 (817), p. 319.

(17) OECD Oil Statistics, Parris, 1972.

(18) Personal Communication with Worthing; V. Gosling, "Fifteen Years of Recovery", delivered to the Institute of Works and Highways Superintendents, 24th January, 1970.

(19) Subha Shenoy, "Pricing for Refuse Removal", Local Government Finance, V.73 (3), p. 105-111.

(20) "Industrial Report by the Paper and Board EDC", July 1970, p.26.

(21) "Waste Paper", The British Waste Paper Assn. London, 1971, from which the background information on the waste-paper industry is derived.

(22) N.E.D.C. op. cit. p.3.

(23) OECD Report, "The Pulp and Paper In the OECD Member Countries", Paris 1972.

(24) Ibid., p.12. But see also J. Fallon, "The Water Lords", Grossman Publications 1971.

(25) A. Porteous, "A New Look at Solid Waste Disposal", Public Cleansing, 64(4) p.152-170.

(26) Barnes, Eggins and Smith, Int. Biodetn. Bull. 8(3) p.112-116 (1972).

(27) Ibid. P.114 and D. A. Dinius and R. R. Oltjen, "Effect of Newsprint on Ration Palatability and Rumino Related Parameters of Beef Steers", J. Animal Sci. 34(1), p. 137-141.

CHAPTER 5: THE RECYCLING OR DISPOSAL OF SEWAGE EFFLUENT.

Introduction.

While this project has not primarily dealt with sewage, this work would not be complete without a short chapter devoted to mankind's oldest pollutant and one that, over the ages, has inflicted the greatest negative spillover. Now, in Western urban areas, the technology of hygienic disposal of human effluent was developed over a century ago; the basis of present technologies is anaerobic digestion on the one hand and biological filtration (through filter beds of crushed stone) on the other; the output, ideally being a liquid effluent of 30:20 standards (30ppm. suspended solids, 20ppm. biological oxygen demand, or BOD) and a sludge which has been freed of pathogens.

Institutional Factors.

Sewage disposal has up to now been the responsibility of local authorities, which, while on the whole conscientious, have hardly been known for their dynamism or innovation record. One reason was, that many authorities have been too small to attract good supervisory staff to their plant; another, and more important, reason is that the public have not in general been interested until recently; "no votes in shit" was a common aphorism in local government politics. Internally, the control of sewage disposal has been in the hands of the municipal engineer, the cleansing officer or the medical officer of health; indicating a dominance by the medical, negative-spillover aspect of sewage disposal (i.e. the first priority being to reduce health risks). The above mentioned professions have also tended to be of a 'maintenance' rather than an 'innovatory' character; the local government service does not attract entrepreneurs or innovators. Finally, drainage, sewerage and treatment have not been a large part of local government expenditure, though from Tables 5.1. and 5.2. below it will be seen that it is expanding. Sewage is capital-intensive; and sewerage fixed-capital has a long life, usually reckoned at 50 years, but useful lifetimes of 70 years and upwards for sewage-plant machinery are not unremarkable. The useful life of a trunk sewer is dependent on the life of the properties it serves and on the loading of the system, not on internal deterioration; lifetimes may be measurable in centuries.

Thus, in this country, the existence of hygienically satisfactory sewerage systems covering a larger proportion of the population than any other country in the world (1), the long life of the capital equipment and the conservatism of the organisations involved has led to a disciplinary narrowness in the field. Cost-benefit analysis has rarely, if ever, applied to sewage projects in Britain. Courses on fermentation processes tend to play a relatively small part in the education of people connected with water pollution or effluent disposal, which tends to be dominated by hydraulic engineering. However, as will be seen, a knowledge of fermentation and microbiological processes is essential when considering the disposal or recycling of sewage or other faecal matter. The new, larger authorities that have assumed responsibility recently however, may have less difficulty in attracting talent to their staffs in the long term.

Sewage as a Mixed Waste.

Sewage is a mixed waste; the main component - 99.99% of crude sewage - is water. Because of man's omnivorous eating habits, his production of effluent is lower than many animals of equivalent size - about 0.13 lb. dry matter per person per day. Owing to Western man's habit of using flush lavatories and then mixing the effluent with that from the kitchen and the bathroom, the result is very dilute - a BOD load of 400 p.p.m. as against 4000+ p.p.m. for dairy waste and 8000 p.p.m. for the output of a pig. (See next chapter). Water, of course, is a desired commodity; sewage plants play a vital role in controlling river levels, maintaining water quality and making possible re-use of water - in total, the daily flow of sewage in 1970 in Great Britain was about 3,100 million gallons, or 14.1 million cubic metres (2) - but the efflux of useable treated effluent tends to benefit communities downstream of the sewage plant rather than the plant itself - "positive spillover", perhaps. Dilution may be aggravated in older urban centres by the existence of combination sewerage systems taking both rain and foul water; these systems are also liable to overflow and discharge crude sewage into water-courses in heavy rain. Modern practice is to install segregated systems - storm water, discharged directly into the water-courses and foul water, treated at the plant.

More serious is the contamination of sewage by toxic industrial effluent, particularly be heavy metals. Not only are toxic sewages resistant to biodegradation, they cannot be spread on land or used as soil conditioner. The Upper Tame Main Drainage Authority, serving a large part of the West Midlands conurbation including the Birmingham District

Council, is a good example of this; it suffers heavily from metal-finishing and pickling-acid residues from Birmingham industry. At the other end of the conurbation, Kidderminster has problems with dyestuffs from its carpet industry. In the long run, the only way of overcoming this problem is to prohibit such discharges while ensuring the provision of appropriate facilities elsewhere. Metal residues, especially, should be recoverable. At present, industrial effluent renders at least one-fifth of total sewage effluent unusable on land.

Pollution via road drains is also a problem; while separate arrangements can be made for oil poured down drains by do-it-yourself motorists (3) - present arrangements are still inadequate - and the oil can be re-refined and metal residues (some 11-1200 lbs. per 10,000 gallons of used oil) extracted, spill pollution cannot be legislated for. Some form of entrapment may have to be provided; perhaps damage to a sewage network or general environmental damage caused by the accidental release of a dangerous substance should be charged to the road-transport industry via an insurance premium.

Recycling Possibilities.

Despite the above dilutions and contaminations, there are factors which favour the recycling of the non-aqueous element in sewage. Firstly, there is no opportunity-cost in transport; the sewage is already collected in one area for treatment. Secondly, unlike the somewhat similar farm waste, the local authorities have access to larger funds and greater expertise than the farmers. Thirdly, despite the remark on page 109 above, it is no longer true to say that there are

Sewage Revenue

(Facing P.113)

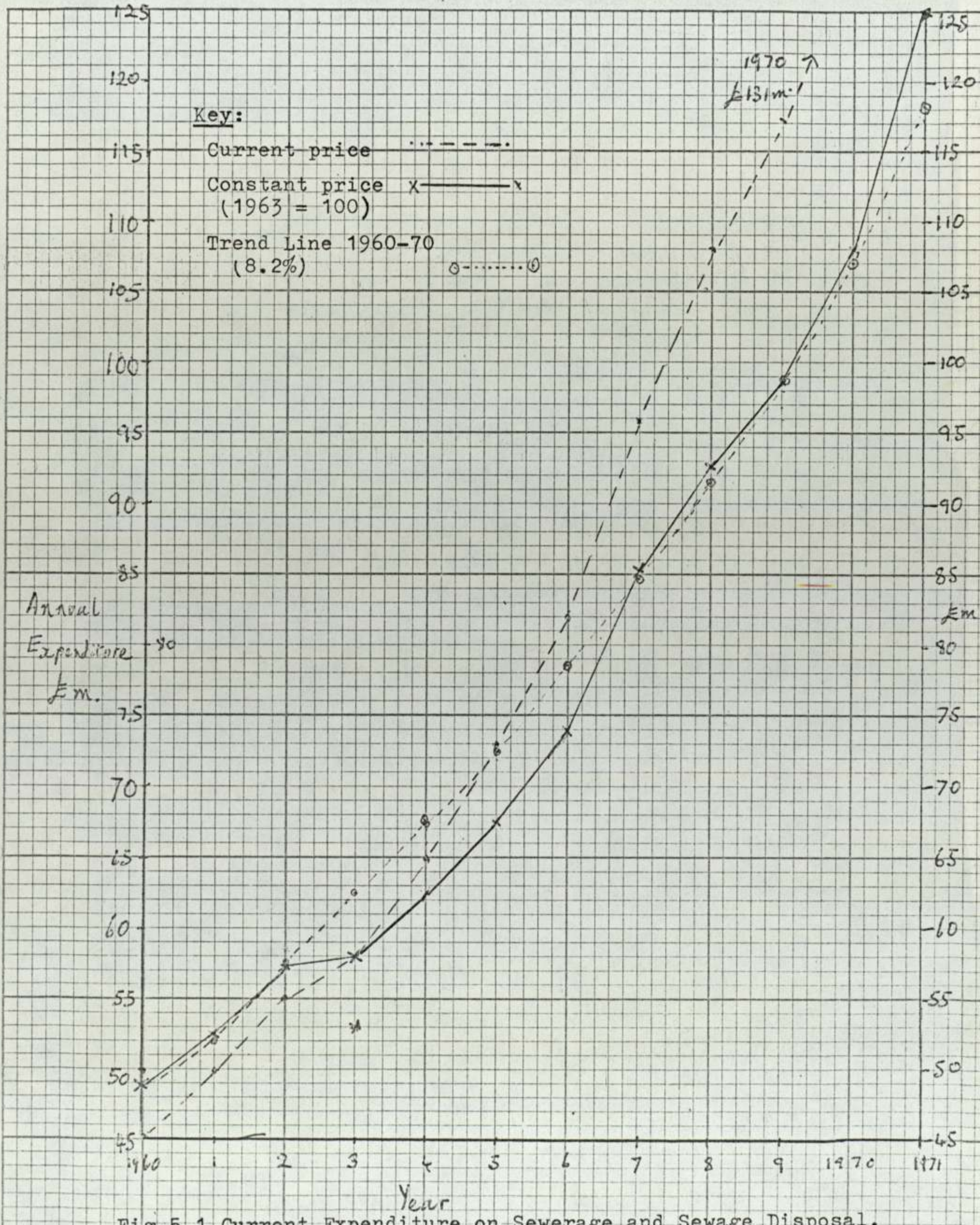
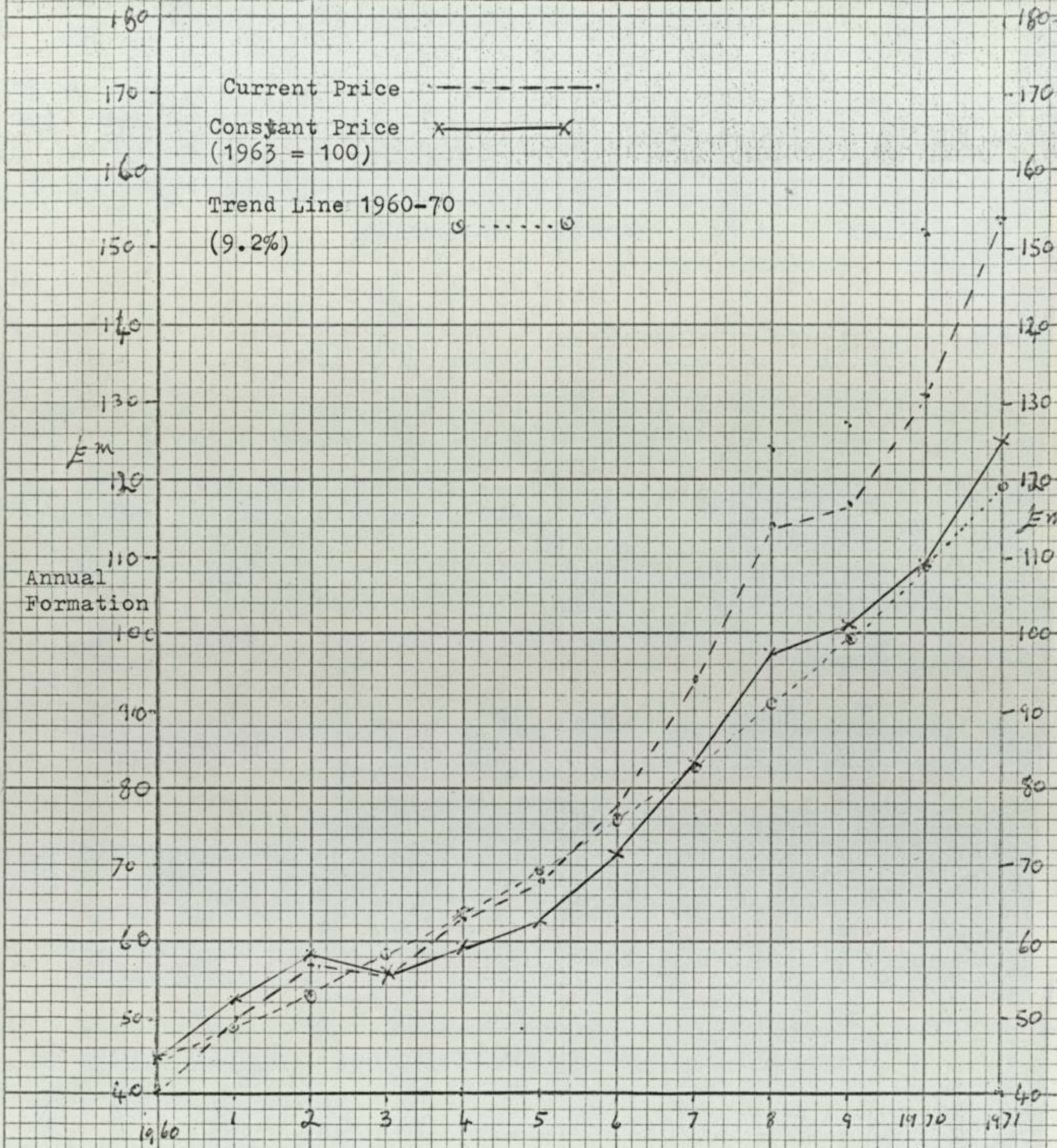


Fig.5.1. Current Expenditure on Sewerage and Sewage Disposal, 1960-71. (Source: Table 5.1)

Fig.5.2. Sewerage and Sewage Disposal - Gross Capital Formation, p.a. 1960-71.



Note: Vertical axis half-scale of Figs.5.1 and 4.1.

no votes in sewage and real expenditures are rising:

Table 5.1.

Current Expenditure on Sewage and Sewage Disposal, 1960-71.

Yr. to 5/4	Current Values £m.	Index	Constant Values £m.	Increase %
1960	45	92.2	49.0	-
1961	50	95.3	52.5	7.1
1962	55	96.2	57.2	9.1
1963	58	100.0	58.0	1.9*
1964	65	105.7	62.6	8.0
1965	73	108.2	67.5	8.0
1966	82	110.6	74.0	9.5
1967	96	112.8	85.2	15.1
1968	108	116.6	92.7	8.9
1969	117	118.5	98.8	6.9
1970	131	121.0	108.8	10.0
1971	154	122.4	125.5	15.9
			Annual Average	9.0

Table 5.2.

Capital Formation in Sewerage and Sewage Disposal, 1960-71.

Yr. to 5/4	Current Values £m.	Index	Constant Values £m.	Increase %
1960	41	92.2	44.5	-
1961	50	95.3	52.5	18.0
1962	57	96.2	58.2	11.0
1963	56	100.0	56.0	- 3.8*
1964	63	105.7	59.7	6.9
1965	68	108.2	62.7	5.5
1966	78	110.6	71.6	14.1
1967	94	112.8	83.5	16.9
1968	114	116.6	97.7	17.0
1969	117	118.5	101.3	3.9§
1970	132	121.0	109.0	7.3
1971	164	122.4	134.0	12.3
			Annual Average	10.5

* Bad winter and deflation, 1962-3.
§ Post-devaluation (Jenkins' "squeeze").

Sources: Central Statistical Service; National Income and Expenditure, 1972. H.M.S.O. 1973.

It is not surprising that the increases in current and capital expenditure in sewage disposal should correlate; sewage disposal is capital-intensive. More interestingly, it correlates well with trends in refuse-disposal expenditure (see Table 4.1.), but does not correlate well with movements in national income, or with capital-formation in the construction sector as a whole, where the average annual capital formation was only 4.6% (see diagram). The exception was the bad winter of 1962-3. Some of this increase would naturally be due to the increasing number of smaller households requiring service and to redevelopment generally, but there would also be some rent-effect on land locked-up in sludge lagoons, sedimentation tanks, etc. Incineration of a substance such as sewage sludge, which contains 43% water is costly and difficult, although some hard-pressed urban authorities have adopted it. Bristol has adopted a scheme using the surplus heat from an incinerator plant to dewater sludge, but the opportunity cost of using refuse for energy may rise too high (see Chapter 4).

Quantities and Uses on Agricultural Land.

The Report of the Working Party on Sewage Disposal (Para. 11, p.64) estimated the sewage flow, including trade effluents, as 3100 million gallons per day (4). England and Wales' annual production of sludge amounts to 1.1 million tons, dry weight approximately. As the Working Party pointed out (5), this quantity of sludge is marginal in comparison to current uses of inorganic fertiliser and as will be seen, it is also small as a humus supply in comparison to the 16 million tons of dry matter in total from farm livestock. Marginality is not necessarily a demerit; at current A.D.A.S. values, the N.P.K. value for sludge may be not inconsiderable; (6):

Table 5.3.

Values of N.P.K. per dry weight of Sewage Sludge.

	Working Party proportions % dry wt.	Value/ton £.p.	Tame Valley proportions % dry wt.	Value/ton £.p.
N	2.4	3.12	1.65	2.14
P_2O_5	1.3	2.60	2.29	4.60
K_2O	0.3	0.21	0.16	0.10
		5.93		6.84

The Upper Tame Main Drainage Authority figures were obtained from an average annalysis of their T.R. Organic Garden Manure, a product discontinued in 1973 owing to high bagging costs, high metal contact and limited off-take of sludge and poor demand. (Also poor sales effort). It will be noted that the sludge is deficient in potash but has a high phosphate content, from the soap and detergent in the in-put. There are disadvantages however; "wet" sludge, 96% water, as extracted only has an N.P.K. value of 23-28 p. per ton. Although some transport cost may be borne as the cost of alternative methods, the transport of dirty water over long distances is not feasible. Many large sewage plants are on the outskirts of towns, away from the agrarian market, although near to the horticultural and garden market. Some 50% of the available sludge, or two-fifths of the total, is returned to agricultural land anyway; one-fifth is disposed of at sea and the other two-fifths is dumped in lagoons, being too contaminated or too far from a market for land spreading; therefore the scope for further returns to land are limited. The risks of metal contamination are high, as witness recent well-publicised cases at Leicester and Croydon, where accumulations of up to 600 p.p.m. of zinc have been recorded. Purves (7) has repeated the well-known case of the accumulation of heavy metals in a cottage garden after 21 years of continual sewage application. Therefore, while land disposal remains of some utility, other methods of recovery will have to be sought.

River Effluent, Marine and Estuarine Dumping.

The suspended solids/BOD load of the effluent does not convey all the information. In some rivers, owing to the quantity of effluent discharged, and to prevent the ingress of nitrite into the water supply, a 10:10: effluent has to be aimed for, not a 30:20 effluent, which adds approximately 25% to treatment costs (8). Others are polluted by sewage works that, through age or inadequate size for present-day loads, discharge effluents of considerably poorer quality than the Royal Commission standard (9). In any case, the Royal Commission that set that standard met between 1898 and 1915 and the importance of nitrates and nitrite-formation was not realised; neither were the effects of nutrient (particularly phosphate) escapes on the process known as eutrophication, or the accelerated algal growth in lakes etc. leading to de-oxygenation and silting. It has already been mentioned that one-fifth, or perhaps some 200,000 tons dry weight of effluent is discharged untreated to the sea or estuaries - which are not covered by the 1876 Act prohibiting discharges of crude sewage into inlane watercourses; according to the Third Report of the (Ashby) Royal Commission on Environmental Pollution (10), the relative contributions of agriculture and sewage to organic pollution of rivers was as follows:

Table 5.4.

Pollutant	Agriculture (tons/ann.)	Sewage (tons/ann.)
Nitrogen	240,000	180,000
Phosphate	7,000	50,000*

* 45% of this is due to detergents.

Source: Third Report of the Commission on Environmental Pollution, Appendix A. p.98.

Heavy-metal pollution is again a risk here. The negative spillover of this pollution into the estuaries and seas is a matter of conjecture. Eutropication of rivers and lakes is a small problem in Britain; lakes are relatively small and away from industrial areas and reivers are comparatively short and fast. Because of Britain's long coastline and cool climate, river bathing is nowhere near as important a recreational activity as in large continental States. There is some negative spillover in estuarine and sea pollution; on the one hand, the dumping of treated sludge from Liverpool and Manchester has created little social cost apart from some algal blooming; most of the gross pollution in Liverpool Bay is due to inshore and industrial discharges. On the other, as in the Firth of Forth, shellfish beds have been lost or rendered unusable by crude sewage discharges (in the case of the Forth, Edinburgh's failed Dano scheme was intended to obviate this); there has also been loss of amenity from beaches being contaminated. Intestinal pathogens (e.g. E.coli) do not long survive immersion in seawater, but there is a risk in estuarine locations and near to outfalls of sewage-borne diseases. More important is, perhaps, the damage to fisheries and aesthetic effects (smells, etc.) The problem has increased in recent years due to the increase of both industrial and residential use of the coastline.

The cost can be estimated; the Ashby Royal Commission (11) estimates the total cost of cleaning rivers to certain standards by 1980 as £610 million at 1970 prices - or 0.15% of GNP per annum - of which £570 million relates to sewage discharges. This is based, of course, on known technologies.

The opportunity-costsof allowing plant nutrients to escape to sea can be quantified, roughly. It so happens that the world's supplies of rock-phosphate are highly concentrated (Skinner,) (12), although phosphates themselves are not geochemically scarce; this lends itself to monopoly pricing. The largest producers are the U.S.A., the U.S.S.R., and Morocco, which latter quadrupled its selling price in late 1973. Production in the U.S.A. has been affected by shortages of oil fuel for excavation; there is a temporary world shortage. At present prices (see next chapter), if 50% or 90,000 tons of nitrogen was recovered, the turnover would be £11.7 million per annum; if the 50,000 tons of phosphate were recovered, at present substitute prices some £10 million would be recovered. If the reduction in negative spillover and the saving in imports were included, this would appear to be an attractive offset to the cost of improving the condition of estuaries.

All this, however, would require new technologies. In view of the high water content of sewage, and the low intrinsic value of the constituents and the relatively small quantities of material involved, biological processes similar to those being developed by Seal and others, at Aston and elsewhere for animal effluent could be used. Hard-shell clams are already being fed in Southampton Water on treated effluent; aquatic algae or higher plants could be grown, using the nutrients, by the "eutrophication" of artificial ponds from which they could be cropped.

Overseas.

The situation is unique in Britain, which has the largest coverage by main sewerage of any country in the world. A future investment of £570 million in existing technology is not large in comparison with an existing capital formation in 1971 of £164 million. In many other countries, especially in many advanced countries that have become industrialised and have grown very rapidly recently, the situation is different. In some cases, such as the United States and Japan, attention was so fixed on the quantities of economic growth per se that quite inadequate attention was given to its consequences; the sewage-disposal problems of Tokyo and the inadequacies of the systems there to handle a daily throughput of 12,000 tons of material have been well publicised (13). The United States was the classic example of the 'cowboy economy' - there was plenty of river to pollute, if one stretch did become foul, there was always another to use. However, the U.S.A. has run out of unused rivers; many American rivers and lakes have become grossly polluted, one well-known example is in fact a fire risk and an estimate was made - admittedly from a slightly suspect source (14) - that it would cost \$100 x 10^{12} to reduce pollution in American rivers sufficiently for them to be used for skin-contact recreation. In comparison, the Apollo space program cost \$29 x 10^{12}. This may be an over-estimation, based on an over-high standard; but this is the kind of expenditure involved in retro-fitting an economy with adequate sewerage. Italy presents an even severer case; it was estimated in early 1972, very roughly, that in order to bring overall sewerage standards to British levels would cost £2,000 million plus an annual maintenance and improvement investment of £100 million - in annual terms, absorbing some 8% of Italy's GNP. Existing arrangements vary from the inadequate to the non-existent; witness the cholera outbreak of late 1973 in Naples. Weak and corrupt government on both the central and local levels has been responsible to a large extent.

The developing countries present a different problem. The development of comprehensive sewerage system is in many cases beyond their economic capacity; but the slum-cities of the Third World demand some form of disposal system. The lack of any pre-existing system, however, gives an opportunity to develop alternative systems of collecting and recycling or disposing of the waste. Where a (genuinely) developing country wishes to install a new system for sewage collection, with recycling as one of the factors, alternatives such as vacuum suction or the segregation of 'grey' (kitchen and bathroom) from 'black' (lavatory) water may be considered; if capital is the constraining factor, improved methods of vehicular collection may be developed. In developing countries, however, the high cost of artificial fertilizers in relation to farm incomes would indicate the development of systems to utilize plant nutrients and facilitate return to land (15).

Conclusion.

This chapter was intended to survey the problems and possibilities of the recycling of sewage or human excrement in order to complement the work done on municipal refuse and agrarian waste, although sewage was not part of the main work.

It was shown that one problem concerning the further recycling of human waste in this country was the conservatism of the public sector dealing with this waste. However, increasing public interest and rising costs and standards should erode this conservatism and encourage the search for an offset to these costs.

Heavy-metal contamination is a large problem in recycling the organic waste from industrial areas; best solved by excluding such wastes from the sewage. The non-mixing principle would dictate this anyway.

New biological recycling processes would be applicable both to sewage presently discharged into the sea in this country and inadequately disposed of abroad. While the financial value of the nutrients in sludge is now considerable, on a dry-weight basis, the water-content of the sludge is high. The quantity of material involved, in comparison with farm animal waste, is not large; sewage is marginal as a supply of nutrients and humus; the best outlook is for processes to utilise and upgrade the material at the point of collection or treatment of the waste.

References.

(1) "Taken for Granted", Report of the Working Party on Sewage Disposal, H.M.S.O. 1970, p.6. para. 30.

(2) Ibid. 1. Para. 64.

(3) Engine lubricating oil drained from sumps by change-it-yourself motorists is something of a bugbear. This waste, being toxic, is covered by the Deposit of Poisonous Waste Act, 1972. According to the Automobile Association publication, "Drive", facilities for waste-oil disposal are still inadequate. Out of 100 garages approached, 8, being self-serve petrol stations, had no facilities, and at three, the oil was illegally dumped on nearby ground. Out of 59 local authorities approached, 41 had facilities for disposal, 10 suggested garages,

2 had no arrangements, (Stratford-on-Avon and Leicester) and 4 suggested illegal methods of disposal (including down drains!) ("Drive", A.A. Publications, p. 89 New Year 1974 edition). See also Pollution: Nuisance or Nemesis? Para. 112, p. 32. H.M.S.O. 1972.

In the U.S.A. the situation is, if anything, worse. The total lubricant market is some 1.1 (American) billion gallons per annum, of which between about 23% and 43% was dumped, according to Environmental Science, v. 6(7), January 1972, p.25, from which the information given on page 112 above was taken. Used lubricant is, of course, a good source of sulphur free oil and new lubricant as well as metal residues, but up until 1973 the relatively low primary price of petroleum led to low margins (in terms of cents per gallon) on re-refined oil. The position will have radically changed, of course.

(4) See (2) above. About 1500 million gallons/day is due to domestic sources.

(5) At most, about 4.5% of N and P consumption. Working Party, p.11, para. 65.

(6) Personal communication, Mr. K. B. C. Jones, A.D.A.S.N. at 6½p. per unit, P at 10 p per unit, K at 3½p per unit.

(7) D. Purves, Environmental Pollution, v.3(1), p.19. In the cottage garden mentioned, an application of 20 tons/acre (8 t./ha) had been applied over 30 years; there were concentrations of 1000 p.p.m. zinc and 1500 p.p.m. lead. There was no mention of the origins of the sludge.

(8) Working Party, op. cit., p.8, para. 47.

(9) Working Party, op. cit., p.9, para. 50. Some 60% of effluent falls into this category.

(10) Third Report of the Royal Commission on Environmental Pollution, H.M.S.O. 1972. Cmnd. 5054. Para 10, p.98.

(11) Third Report, ibid., p.64, para. 204.

(12) B. J. Skinner, "Earth Resources", Prentice-Hall, 1969, p.89. Table 5.3. For further discussion on phosphates, see Chapter 6 this thesis.

(13) "Times" article (Anon.) 1971. Tokyo's generation is of the same order as London's, but has not as yet developed the sewerage or treatment systems to deal with it. At the time of writing of that article, the main method of disposal was dumping at sea.

(14) "Sunday Times", 14.10.72., reproducing Wm. F. Rockwell,Jnr. in Automotive Engineering, v.80(6), June, 1972. Suspect; U.S. industry, especially automotive, has fought too hard, too long and too foully against any form of control.

(15) F.A.O. Report, 1972.

CHAPTER 6: AGRICULTURAL WASTES: RECYCLING AND DISPOSAL.

General Introduction.

This chapter will discuss the organic wastes arising from modern, temperate-zone agricultural practices and the problems connected with the re-use and disposal thereof. These problems will concern the transport and processing of the waste and the possibilities of biological - mainly microbiological - upgrading of these wastes into useful products.

Some issues referred to in previous chapters will also be discussed in further detail.

Historical Background.

The four-course rotation, as practised from the latter part of the eighteenth century to the 1930's tended not to produce any waste problems as such. Except in the wetter lands of the west of England and Wales and the hill farms, most farms were mixed; all the more so after the agricultural depression of the 1870's that followed the opening-up of the North American Prairies and, later, the wheat lands of Australia, which favoured the conversion of much arable to pasture. Until the late nineteen-fifties, there was no zero-grazing of livestock; cattle spent much of the summers out of doors and spread their own muck; much poultry was free range and the intensive animal unit of any size was a rarity. When labour was relatively cheap and abundant, manual "mucking-out" of dairies, cowsheds, pig pens and poultry houses was not a problem; and although farmyard manure is not the best way of using the available nutrients, it could be stacked and composted and be available when it was possible to spread it. Artificial fertilizers were not available before the end of the nineteenth century anyway; and included horse manure. Straw, too, had its uses; with traditional methods of harvesting, either by hand or using the early reaper-binders, cereals were cut, stooked and then carted to the threshing-floor, the straw along with the grain; the opportunity-cost of transport of straw from the field did not arise as it does with combine harvesting. There were not only on-farm uses for straw, such as animal and human bedding, thatching (where reed thatch was too costly or unobtainable), making cob walls (straw intermixed with mud - used before the advent of rail-transported mass-produced bricks) or as a maintenance-feed for horses and cattle, but off-farm demands for straw as well. The urban horse provided a large market prior to c. 1905; although railways handled inter-urban traffic and bulk goods, distribution traffic from the goods stations, intra-urban freight and - especially in London, where many areas remained without tramways and steam trams were never adopted - urban passenger transport were monopolised by horse-drawn vehicles. Small additional markets were provided by hat manufacture.

During the period 1950-1971, however, various changes occurred, and various long-term trends rached a culmination, that created waste problems on the farm:

(i) the drift of labour from the land reached its ultimate; the proportion of the labour force employed directly in agriculture fell to around 2½% in the U.K. - the lowest in the world (1). Labour is now neither abundant nor cheap;

(ii) the horse, having already disappeared from the town, almost disappeared from the farm, reducing the demand for straw;

(iii) as a precaution against the severance of food supplies from overseas by war or other cause and because the former free-trade or imperial trade principle whereby Britain exported manufactures to pay for food was no longer applicable, successive governments encouraged investment in British agriculture by subsidy;

(iv) there were various technological changes that were encouraged by this capital investment - compound fertilisers, pesticides, herbicides, and the machinery to apply them - that made it no longer necessary, or apparently necessary, to rotate crops.

This led to the development of monocultures of arable crops and cereals in the east of England and of livestock in the west of England, Wales and much of Scotland. Artificial fertilisers were subsidised to the extent of £2.50 per ton - until 1971-2 - whereas manures received no subsidy; in any case, the new geographical separation of arable and livestock broke the original cycle; the eastern counties have a surplus of straw, much of which is currently burned, while those further west, especially the ten per cent of holdings considered 'intensive', tended to have a deficiency of straw and, if not a surplus of animal waste, labour-cost problems in spreading it on land; the cost of spreading the equivalent N.P.K. values in artificial fertilisers was far less than that of spreading manures. Finally, the rise of the supermarket and the convenience-food industry has encouraged the rise of the intensive (i.e. land-intensive) animal unit, especially in areas near urban markets, with its own disposal problems.

This was the position in 1971, when the work first started; an agriculture heavily reliant on external raw-material inputs which created wastes which were giving rise both to internal disposal costs and to negative externalities - such as run-off of nutrients into streams, causing eutrophication, nuisance problems where intensive units were sited near outer-suburban and recreational areas and nutrient-logging in low-lying land; the problem then was to discover whether the material could be used in an alternative process to land-spreading, or rendered such that the return of the nutrients - including any humus-value - would be of less cost to the farmer than a hygienic method of disposal of the waste; the problem in both cases being that, the value of the annual product of any one farm animal (say) being so low and its waste product being so large in volume that human-sewage techniques of disposal were inappropriate (2).

Present Considerations.

Since 1971, which was "something of a turn-round" (3), the situation has altered, as could have been foreseen. The subsidy on inorganic fertilisers in the U.K. was withdrawn in 1971-2; in late 1973 Morocco, the third largest world producer of rock-phosphate, quadrupled its export-prices - at a time when U.S. phosphorite quarries were finding their production restrained by fuel shortages. At the same time, the same hydrocarbon shortage restricted nitrogen-fertiliser production in the U.S.A. and forced distributors in that country to import from overseas, including from Britain, where natural gas is used as the raw material source. This has caused a rise in the price of artificial nitrogen fertilisers. In both cases, the magnitude will be given below, in Table 6.1. Apart from such obvious rent-effects in non-renewable resources, there have been some probably short-term phenomena; the complete failure of the cereal crop in the U.S.S.R. in 1972, the washing-out of much of the soya crop by the Mississippi floods in 1973, the American Mid-West drought in 1974, again badly affecting the soya crop, together with other crop shortfalls, have caused the price of soya-bean meal to rise drastically - see Table 2.2. During 1972-3 the Peruvian anchoveta fishery also failed, for reasons not understood at present, although it has since recovered.

Not only have there been shortages affecting the affluent West; although the demand for food by the indigent Third World has been rendered ineffective in market terms by poverty, most authorities agree that many tens of millions of the populations of the poorer parts of the world, especially in southern Asia, have been kept alive by donated surpluses (4). With the high probability (5) that the total world population will rise to 7,000 million by the end of the century, and the almost equally high probability that the agricultures of these countries will not be able to supply the food needs of their populations for a whole variety of reasons, there will no longer be any large food surpluses as such and any food for donation to a country in danger of famine will have to be drawn from stock for current consumption at market price. With increasing, though debated, (6) shortages of proteinous food (for the benefit of orthodox economists, a "food shortage" will here be defined as a shortfall of food supply below the biological necessity to maintain health in a population so affected), the use of those materials arising on farms now regarded as waste is to be expected.

The re-use of wastes arising on farms is essentially a land-saving device, the product substituting for presently-used crops. The strategy used is basically that outlined in Chapter 1 - to reinforce a natural loop diverting material out of the decay cycle into the metabolisation part of the cycle, by the use of saphrophytes etc. The object of this chapter is to show how best this may be done.

Farm Animal "Wastes".

These are no longer wastes in the true sense of the term:

Table 6.1.

N.P.K. Values/Wet Ton of Animal Wastes, 1970 and 1974.

	Available Nutrients (units/ton) N	P_2O_5	K_2O	Price 1970 £.p.	Price 1974 £.p.
Poultry	28	20	20	2.03½	4.52
Cattle FYM.	8	3	9	0.56	1.13½
Pig FYM.	8	6	6	0.59½	1.33

Table 6.1a.

Substitute Prices of Inorganic Fertilisers, Pence/Unit.

	1970	1974	% increase
N	4	6½	162
P205	3	10	333
K20	2	3½	175

Sources: Nutrients from MAFF Short Term Leaflet 67, 1969. Prices - 1970, from K.B.C. Jones and C. T. Riley, "Origins and Nature of Farm Waste", pub. Farm Waste Symposium, University of Newcastle, 1970; 1974, personal communication from Mr. K. B. C. Jones.

The N.P.K. value of an organic fertiliser is not a wholly satisfactory basis for computing its value. Firstly, only those nutrients considered immediately available, because water-soluble, are valued; there may be a slow-trickle effect from the release of the "unavailable" nutrients; secondly, there is a certain trace-element content and there is the humus value. Humus is a decay product, apparently derived from lignin, which is beneficial to soil structure in that

(a) being hygroscopic, it aids water retention;

(b) it appears to have some chelating properties which enable plants to utilise soil minerals, especially trace elements more efficiently, even when the minerals concerned are deficient in that soil (7);

(c) being somewhat adhesive, it causes soil particles to clump together and improves crumb structure.

It is not strictly essential, as plants can be grown in hydroponic culture without humus or organic material; but hydroponic culture is not practical for external or large-scale use. Organic material in the soil, moreover, acts as a substrate for various bacteria and fungi which form symbiotic associations with higher plants, many of which are of economic importance. The biological functions and importance of humus, however, are at present indeterminate; it is very difficult to put an economic valuation upon it. Such valuation would in any case vary with soil type. However, the N.P.K. values at present are such that the A.D.A.S. considers that it no longer has a "waste" problem with farm animal wastes.

There are areas such as The Netherlands, where the accumulation of residues from intensive livestock farming, coupled with the low-lying nature of the land, the high water table and the ingress of pollutants from the Rhine, has created a serious disposal problem (8). In the United States, there are problems with feedlot run-off in the mid-West and nitrate fertilizer run-off; exacerbated by the natural "gutter" formed by the Mississippi-Missouri and St. Lawrence basins (9). In Britain, however, apart from the ten per cent of holdings classified as "intensive", there is no overall shortage of land for manure-spreading - and that is true for the world as a whole (10). The main problems are concerned with:

(a) the application of this material to the land; and

(b) - an offshoot of the 'surplus' situation of three years ago - the use of this material as a raw material for the production of an artificial feedstuff.

This will be considered under various headings.

(a) Poultry Manure.

After an initial assessment, this project decided to treat the problem of poultry manure as secondary. The high N.P.K. value of poultry manure, the low moisture content (about 76% fresh) and relative ease of drying and absence of a liquid fraction have led to much work in many centres being done on drying processes. Willetts (1972 (11)) reported that there were sixteen systems for drying poultry manure on the market, which was consequently overcrowded. Dried poultry manure was claimed to be selling at £14 per ton in 1971 and in excess of £30 per ton in March 1974 (12); indeed, there have been allegations that in the present depressed state of the industry, the income from DPM sales per bird exceeded income from sales of eggs. The prices obtained were partly the result of the use of dried poultry manure as cattle feed additive, despite the objections of the MAFF to the feeding of animals with non-heat-treated or non-pasteurised animal wastes on veterinary grounds. Therefore, although some 50% of poultry on 3.5% of the holdings fall into the "intensive" category, that is, with insufficient land for the land-disposal of animal wastes, poultry will hereafter be dealt with only in passing.

(b) Mammalian wastes.

In practice this means waste from pigs and cattle; owing to pathogen and other problems, sheep are not kept on a zero-grazing or an intensive system.

Mammalian wastes have two components - a liquid (urine plus a liquid fraction from the faeces) and a solid. In conformity with the principle of the non-mixture of wastes, it is best if the two components are treated separately. (Seale, 1973 (13)). In some circumstances, it is possible to separate the liquid fraction from the solid by means of straw filters - in the eastern parts of the country, the straw is itself a waste - especially where cubicle housing is used. The liquid fraction may be disposed of onto land without the necessity of using large-bore slurry pumps or guns or the unpleasantness of handling slurry - or the expense of slurry tankers. The solid component can be removed, with little more labour than is required for a slurry system, and either biodegraded by thermophile fungi in a solid substrate fermentation system at c.48 C, to produce a protein-supplement feedstuff, the high temperature being needed to prevent pathogen carry-over. Alternatively it can be biodegraded, dried, and stored until it is possible or desirable to apply to land - it must be remembered that for five months in the year in this country, it is not possible to spread material on land. Liquids, however, may be sprayed on at any time.

The two present favoured methods, the farmyard-manure system and the slurry-system both have disadvantages. The farmyard manure system does have the advantage of separating-out and consolidating the waste; but it is too costly in labour - and tractor-time for large holdings. Moreover, nitrogen, especially tended to be lost, both because the liquid component was lost through the drainage system and because trampling on the bedding by the animals tends to compact the straw-faecal mixture, which gives rise to anaerobic conditions, leading to evolution of ammonia to the atmosphere, inefficient degradation and the retention of pathogens. FYM systems have their defenders, however, among practising farmers (14).

Slurry systems have objections almost as great. They contravene the basic principle of the non-mixture of wastes in that they attempt to handle the liquid along with the solid; although labour-time is saved in "mucking-out" animal housing, Willetts (15) has reported on the very high cost of tanker-spreading. In the case of dairy waste, the removal of effluent may range from £4.08 per cow/year to £12+ per cow/year (16). Pathogens, particularly Salmonella spp. may be spread by raw slurry on land (17); large quantities of slurry also tend to become anaerobic and septic, causing objectionable odours. Apart from the labour-cost point, slurry systems seem to be losing favour (18).

Hygienic-disposal methods, such as the Pasveer trench or the aerobic lagoon have definitely lost favour. The BOD load of cow effluent is around the area of 4000 p.p.m; pig effluent has a BOD load of 7000-8000 p.p.m. depending heavily on the feeding regime (19). The quantities produced over a given time are also large; one dairy-cow, producing 15 tons of fresh, wet manure annually, produces approximately the equivalent of 10 human beings, or 7 to 9 pigs. Not only is the hygienic disposal of this kind of effluent expensive - at least £5/cow/year - and full anaerobic-digestion systems impossible to contemplate on farm incomes, (20, 21) but the opportunity-cost of the manure is approximately £17/cow/year. In fact, farmers are now removing sludge from aerobic lagoons for spreading on land, for the nutrient value (22).

(c) Intensive Units.

Defined, for the purpose of this thesis, as those units where the area of land is insufficient for the absorption of all the effluent produced without undesirable effects such as excessive run-off into watercourses, these amount to 10% of all livestock holdings in Britain. The minimum density for a unit to be regarded as truly "intensive" is the equivalent of one dairy cow or 7-9 pigs per acre of arable or available land; 2% of cattle holdings with 4% of the number of animals and 16% of the pig holdings fall into this category. Rather less than this proportion has an outstanding problem with waste, as many make disposal arrangements with neighbouring farmers. Large intensive units, those with no suitable land nearby and those in an "exurban" situation, i.e. near residential areas whose inhabitants, not being country-people, are liable to complain about the smell or take legal action, have outstanding problems; and these offer a market for processes of re-using effluent by means other than land-spreading. As a sole market, however, its future may not be too promising; the rapid rise in feedstuff prices may tend to favour units with sufficient land attached to provide at least part of their own feed requirements; many intensive-unit companies were set up to attract City finance rather than to exploit any agricultural advantages of intensive units over other forms. That is not to say that zero-grazing, battery farming or any of the technologies associated with intensive livestock farming would be abandoned unless there are pathogenic, toxicological or marketing reasons why they should be.

However, all animal holdings have the problem of the storage of waste pending disposal to land; and the opportunity still arises here to develop an alternative process. The opportunity-cost of using the effluent for other purposes is approximately £1.33 per wet ton. The cost of the main animal protein feedstuff, soya bean, has tended to rise for a long time:

Table 6.2.

Prices of Soya Beans etc. Imported into U.K. 1967-72.

	Quantity Imported (met. Tonnes)	Total Cost \$.US '000	Average Price/Ton \$.US	£.stg.(@ \$ 2.40)
1967	252795	29,221	115.5	48.2
1968	240662	26,051	108.2	45.0
1969	322893	34,378	106.2	44.3
1970	364713	41,241	113.0	47.1
1971	306534	39,598	129.8	53.8
1972	538540	72,565	135.0	56.3
1973*				80.0 -120
1974*				80.0

Source: FAO Traded Commodities Return, 1972 (pub. 1973).

* Market quotations.

A perfect illustration of the thesis of Chapter 2; low prices in the early stages of the exploitation of a commodity, leading on to the 'discontinuity-point' and a large increase in prices in a short time. The floods of 1973 and the drought of 1974 only partially invalidates the argument; in 1972, the total world export-trade in soya beans and products was fractionally under 13.8 million metric tons, of which some 11.9 million tonnes or 87% originated in the U.S.A. In 1973, the Nixon administration restricted exports for some time, in order to keep down domestic prices; dependence on such a single source supply is dangerous. Cultivation is increasing elsewhere, but mainly for home consumption.

Claims that intensive cultivation of the tropical rain forest areas, especially of the Amazon (23), could satisfy many vegetable-protein needs must be discounted; there are a whole range of biological and human problems to be overcome in the countries concerned, of which the human problems are the more intractable. Recent history has also demonstrated the utility of encouraging at least a partial independence of imported supplies for strategic and balance of payments reasons; the continued growth in world population must also be considered.

As for the potential market compared with the likely supply, at the most approximately 270,000 Imperial tons of dry matter from cattle and 660,000 tons from pigs are produced in the problem sector; at recovery of one-half of the dry weight, some 465,000 long tons (474,000 metric tons) would be available at most; if soya meal was substituted for, it would not overload the market.

(d) Processes.

The essential requirements of a successful process for the use of farm animal wastes are:

(i) there should be a reasonable gross profit between the opportunity cost of using the manure for this purpose and the expected sale price of the product, or the substitution price of the primary feed;

(ii) it must be on an on-farm or near-farm scale. Mammalian faeces contain 85-90% water and transport over any distance is not only costly but infeasible; sepsis is liable to occur;

(iii) being on farm, it must be technically simple. Despite the high level of technical skill and sophistication of British farmers, any on-farm process will have to be rugged enough to withstand operating conditions, be simple to operate and will have to consume the minimum of labour-time;

(iv) if the product is a feedstuff, pathogen transmission must be prevented. This is especially true of thermo-tolerant pathogens such as Aspergillius fumigatus. If a biological process is used, it is desirable that it be thermophilic - operating at temperatures above 40 C and preferable around 48 C (Seal, 1974) (24). It may very well be that an additional pasteurization process may be needed in order to meet the Ministry of Agriculture's objections to the feeding of non-treated, waste-derived materials to livestock. The Waste Food Order, 1973, prescribes that all waste meat products and all foodstuffs that have been in contact with meat should be heated throughout to a temperature of 100 C for a period of not less than one hour prior to feeding and that only approved treatment plant should be used;

(v) protein content, in order for any foodstuff product to be attractive, must exceed 20%. Microbiological protein, while having adequate quantities of lysine, tends to lack methionine; this can be added to the animal's diet by other means, or to the feed itself at some little cost;

(vi) the process must not itself give rise to a waste problem. No organism will convert the whole of its substrate; it is desirable that any residue should be biochemically stable and storeable before disposal.

The solid-substrate fermentation processes being developed by Dr. Seal and his colleagues at the University of Aston seem to fulfil many of these requirements. These consist, briefly, of culturing thermophilic fungi on the separated solid component of the waste in a tower fermenter with trays stacked one above another. The requirement of technical simplicity is met; no aeration mechanisms are required as with liquid-substrate processes. As discussed in the last chapter, owing to the heavy starting inoculum, complete sterility is not required; owing to the interposition of the fungal stage, and the thermophilic nature of the process, pathogen risks are reduced. The bulk of the waste is reduced by 50% and is grindable, storeable and transportable for land disposal; it is also inoffensive when applied.

At this stage in the research, a cost-benefit analysis is less easy. Benefits depend on protein quantity and quality, with the minimum proviso of 20%. Rough costings indicate a production cost of £28 per ton at 1973 prices, on a pilot-scale; which, when substituting for a product with a present price of £120, gives some room for cautious optimism.

The Wolfson Foundation is also known to be investigating similar schemes.

Other processes have been investigated by other researchers. Up to the present, anaerobic digestion has been investigated by several authorities. However, the process is wasteful in material, has a tendency to be unstable and problems have arisen on pilot-scale plants with flocculation, the blocking of outlets by husks, straw fragments and other undigested materials (human-sewage plants can afford screens to remove contraries), the difficulty of maintaining the pH between certain narrow limits where methane evolution is desired and the cost of heating and mechanical agitation (25).

Microbial methods are not the only ones of creating useable protein out of this waste. Cophrophilic insects, which naturally use cow-pats and other animal droppings as their ecological niches, may also be used, but, surprisingly, little work has been done. At Beltsville, N.Y., U.S.A., under USDA auspices, housefly larvae, in perforated-bottom trays, were used to biodegrade poultry droppings; on pupation, the larvae burrowed through the perforations into a lower tray to pupate, six days after hatching, where they were harvested. The pupae were dried and fed back to the poultry (26). It was found that the tunnelling of the larvae through the substrate facilitated aerobic degradation (but not thermophilic); also the process facilitated drying. In another set of experiments, earthworms were used to convert ruminant manures, dried after harvesting, and successfully fed to cats (27). The quality of this animal protein is not in question; the protein content of the product is in the region of 92%. Disadvantages may arise in conversion efficiencies - insects are motile and thus may use some of the nutrient-value in the waste for their own motion - and in the management of insects; how to prevent flying imagos (adult stages) from escaping and acting as carriers for mammalian pathogens; control of insect pathogens; disentangling the insect from its substrate at cropping time and ensuring that there is no pathogen transmission back from the waste to animals or human beings; and the area of tray space needed to breed the insects may be large. However, the field may be worth investigating - certainly, other species may need to be evaluated - and it is basically the fragmentation of the biological sciences that is hampering efforts in this direction. A joint evaluation of mycological/microbiological and entymological processes, which may not be mutually exclusive, may be warranted.

On the other hand, "wastelage" systems, involving the feeding of an animal on its own faeces without the interposition of another organism, have little promise (Cornell conference (29)), either biologically, since the wastes have to be treated chemically to render the remaining cell-wall material available to the animal, or economically; adverse effects have been shown on weight gain. Even dried poultry manure has its problems; although it can be fed to reminants in quantities of up to 10% by weight in the diet without affecting the animal's weight gain (30), care has to be taken to avoid pathogen carry-over (31). In any case, if either of these processes are used, there is the risk of arousing emotive public revulsion, which could result in blanket legislation against good and bad waste-reclamation practices alike; the State of New Jersey has already banned the direct feeding of animals on wastes of this kind (31).

In conclusion, then, there is no animal "waste" problem, except where institutional arrangements (i.e. intensive farms) have created one; there is mainly the problem of the more efficient use of a substance at present finding a rather low-level use. There is every case for re-use and none for hygienic disposal, even if such were possible.

Farm Vegetational Waste.

Being comparatively innocuous as a source of pollutants, not carrying the health risk nore theobjectionable smells of animal waste, with certain exceptions, vegetational waste has not attracted the same interest as its animal counterpart; and these exceptions are either nuisances because of quantity such as straw or liquors from processes connected with vegetables such as silage effluent or food-processing waste.
The negative spillover from the disposal of vegetable wastes is, in general, small; the arising is seasonal (in temperate climates) and short-lived. The case for the re-use of waste vegetation depends largely on cost-benefit grounds; the benefit to be derived will depend on the demand for the waste that can be created from new outlets and processes or will arise from the needs of expanding populations.

It is not certain how much waste biomass is created in crop growing; estimates can be made of the proportion of the crop that actually goes to "waste" in that it is not used, such as one-third of a potato crop (represented by the tops) or two-thirds of a cereal crop (represented by roots, straw, leaves, chaff etc.), but it is as yet difficult to determine how much is required as humus and how much is really available for other uses. However, growing world populations have given an incentive to research into ways of land-saving generally, and the reclamation of vegetable waste, as much as of animal waste if not more, is a land-saving device, "land", including fossil resources. The recent rise in petroleum prices has stimulated interest in non-agrarian products from agrarian waste (33).

However, reclamation of vegetation waste is far from easy; in addition to the low off-setting negative spillover from disposal, there is a high opportunity-cost in collecting crop wastes from the fields. This is especially true of straw and is in contradistinction to all other wastes dealt with so far and, generally, to industrial wastes. Also, the waste arises at the time the farmer can least spare resources to deal with it - at harvest time. Some of the wastes, indeed, are so spasmodic in arising that reclamation is impracticable. Silage effluent, for example, causes more effluent problems to river boards than does intensive animal husbandry (34); but fortunately, the discharge can be prevented by wilting the grass immediately before making the silage (difficult in a wet year) and thus retaining the nutrients. Silage liquor has a BOD of 40,000 p.p.m. - extremely high.

(a) Straw.

Probably the largest single category of waste vegetation in this country, approximately 6-8 million tons is produced per annum, depending on estimate. According to the Department of Agriculture, the yields of straw per acre during the period 1960-70 was as follows:

Table 6.3.

Yields of Straw per Acre. (cwts.)

	Arith. mean.	Standard Deviation	Low.	High.
Wheat	15.7	1.89	12.0	18.8
Barley	13.2	1.06	10.8	14.9
Oats	17.8	1.59	15.5	20.0

Source: (derived from) Agricultural Statistics, 1969-70, Table 56, H.M.S.O. 1971.

However, according to the National Farmers' Union's Working Party on Straw Disposal (35), in 1972 there was a total straw yield of 9,306,000 tons of straw, using a rule-of thumb estimate of 23 cwt/acre. The N.F.U. considers that the Department's samples were too low (36) and reports yields of 2½ tons/acre for isolated localities. This is typical of the state of data in waste materials. The N.F.U. Report claims that some 3.57 million tons of straw is actually surplus - some 39% of production. Because of the geographical specialisation into arable and pasture, most of this surplus arises in the eastern counties:

Table 6.4.

Proportions of Straw Burnt.

None:	Cornwall, Wales.
5%:	Devon, Somerset, Derbyshire, Lancs., Cumberland.
75%:	Cambridgeshire.
70%:	Hunts, Beds., Part of Holland (Lincs).
60%:	Suffolk.

Harvest and transport costs are the main obstacles. The cost of collection from the field, including baling, has been estimated by the N.F.U. at £6.80 per ton at 1973 costs, (37), by "Farmer's Weekly" at £7 per ton at 1972 values. This is equivalent to some £4.50 per acre; for costs will vary with labour - and harvester-time. Burning, on the other hand, costs some 5.4 pence per acre (38), including the costs of reasonable fire precautions. Any social costs will be discussed below. Transport costs are a greater obstacle still; in 1968, according to a D.o.E. estimate of the time, transporting a load of 10 tons on a 10-ton payload vehicle cost £2.04 for a fixed cost plus 31¼p. per hour run - each figure, being per ton. An hour-run figure may be a better indicator than a mile-run figure, given the tortuous nature of rural roads. At 1st February 1974, "Farmer's Weekly" quoted ex-farm straw prices of £7 per ton in the Eastern Counties to £13 per ton in Cornwall - an indication of transport costs over a distance. Because any process involving an upgrading of straw involved a weight reduction and a gain in value per ton, it is logical to site any process on the farm or near the farm(s) where the surplus arises. An opportunity-cost of from £8-£11 per ton may be expected, the lower figure for an on-farm process, the higher for an off-farm process.

There is the question of the social cost of burning - the risk of fires out of control, the smoke drift, loss of hedge-rows and wild life etc. It has been suggested, because of the damage caused by the more negligent farmers, that straw-burning should be banned entirely, but there may not be any economic justification for it. The burning is seasonal in nature; the cost would include the risk, during that period, of smoke drifting over roads and causing accidents; the nuisance caused when burning close to residential areas; the "insurance" risk of uncontrallable fires (partly internalized by precautions); the damage to permanent vegetation (indistinguishable from that resulting from other aspects of modern farming practice). There would probably be a case for partial restriction of burning within a certain distance of residential or recreational areas, aerodromes, motorways and "A" class roads, but not a blanket restriction unless the activities of a delinquent minority indicate such action.

To give some indication, the cost of Fire Brigade calls to straw-burning was estimated at £30,000 in 1972 - approximately 0.9p. per ton burnt. Future costs and legislation will depend how far the farming community adheres to the N.F.U. recommendations on straw burning.

Straw burning appears to have little adverse effect on the organic content of the soil; the roots still remain. Many weed seeds are destroyed during burning, although only those pathogens which can survive on dead straw are reduced by this method. Ploughing-in requires previous chopping; chopping requires expensive equipment, consumes fuel, is difficult on damp straw and costs over £2 per acre. Neither the Ministry nor the N.F.U. recommended it for general use. The carbon-nitrogen ratio, at 100:1 is poor, so that additional nitrogen would be required to be ploughed-in at the rate of 60-80 units of nitrogen per acre - at least, initially. Ploughing-in and direct drilling through chopped straw increases the risk of pathogen infestation. Thus, for disposal in the field, there is no alternative to burning; and uses off the field would have to bear the whole cost of haulage. (39, 40).

Since straw is nutritionally deficient, it cannot be used as a feed alone, though barley straw is used as a "maintenance" feed for horses. The vast bulk of the straw is used for feed and bedding; there is a tendency for farmyard manure systems to return to favour, but the separation system investigated by the Biodeterioration Information Centre and described above uses straw as a filter in a rather more effective way. Another project being investigated by the University of Aston involves the use of straw alone as a substrate; promisingly, a fermented rice-straw product is already manufactured in Java for human consumption and has found a place in the traditional diet there (41).

Non-agrarian uses for straw are of only local significance and are liable to remain so. There is a growing use of straw-board and given present pulp supplies, there is discussion of the revival of a straw-paper industry in this country. However, like many agrarian wastes, that 3.57 million tons is large enough to be a considerable cause of concern, but too small to be an industrial bulk material.

Whether any process developed will be on-farm or "near-farm", i.e. concentrated in a local factory, will depend on whether:

(i) farm operation can be kept within the required parameters for adequate quality control, and

(ii) whether the return from centralised operation would cover the added transport costs of raw material in and finished product out and whether there would be any advantage from scale economy.

Other Vegetational Wastes.

These include pea vines, potato and beet tops and other unused green parts of plants. Silage liquor has already been dealt with. Unlike straw, very often these wastes cannot be stored readily because of their liability to putresce; or the volume of their arising, although significant enough to be a nuisance on the farm or horticultural holding, is not significant enough to develop a process for. At present, many of these wastes can be expected to be composted and returned to land (42).

The most significant group of non-cereal plant wastes are the wastes from the food-processing industry - from canning plants, frozen-food establishments, alcoholic-beverage plants etc. There are no significant wastes from abbatoirs or the animal-food processing industry; all of an animal can be used "except its squeal". Now, these essentially industrial wastes tend to be concentrated at few points of generation; the main barrier to their utilization appears to be their heterogeneity. Beet pressings, brussels sprout liquors and waste, and winter cabbage liquor in winter; potato peel in spring and autumn; all these wastes are seasonal in output; if these wastes are degraded in open conditions, the microflora will vary with season. The carbon/nitrogen ratio is very poor and the BOD load very high (43); indeed waste disposal is currently a cause of concentration in the industry.

Utilization has been very much hindered in the recent past by these factors and by the scale of operation - too small an output of waste to satisfy the demands of the producers of bulk chemicals such as ethanol and too great competition from homogenous and, until recently, comparatively cheap petroleum feedstocks (43). However, the need for "land-saving" and the growing scarcity of petroleum may encourage this source of material to be developed.

Discussion.

It has emerged from this chapter that all the waste problems arising on farms - food-processing wastes are of a different order - have arisen because of certain trends in modern agriculture - the dissolution of the former mixed-farm, four-course rotation and its replacement by basically monoculture specialisations; arable farming in the east and livestock in the west of Great Britain and the emergence of the intensive livestock unit. These trends have not been confined to the United Kingdom, but have emerged in continental Europe and the United States.

In the United Kingdom especially, and to a lesser extent in the United States, this has been due to a shortage of labour, encouraging the substitution of capital for labour and to the development of techniques to maximise labour-time productivity as much as, or even more than, land-area productivity. It has also been due to the availability of inputs, either from overseas or from fossil-fuel sources or other non-renewable origins, that were homogenous and were capable of being used with less labour than the often bulky, heterogenous and "sticky" animal-wastes; inorganic fertilisers were capable of being sprayed, puffed or injected onto the land in low bulk and high concentrations through easily-available spray nozzles or dusters - in extreme examples, with large farms, aircraft were employed to apply the fertilizer, such was the need to economize on labour-time. Similarly, the intensive animal unit was encouraged by the availability of soya bean meal and other feeds at reasonable prices, by the need to save labour in the unit, by the demand for standardized products from the retail trade (and the need to save labour there, too) and - an institutional factor - by the need to attract outside finance.

Now, these external inputs are no longer low-cost and easily available; and, as far as animal waste is concerned, relative costs are once again indicating using this material and not disposing of it, hygienically or otherwise. The problems are, to render this waste into such a physical state that it possesses no more awkward handling characteristics than the pure liquids and the pure solids now being applied and to minimize loss of nutrient, and to increase the value to be gained from using the solid,component of the waste by upgrading. There is also the special problem of those units who have insufficient land on which to spread their waste. As shown above, there are processes that can perform this function.

To some extent, the problems of waste utilisation on farms might be alleviated by a partial return to a mixed regime, albeit still using modern techniques. Straw from the arable sector could be used as filter-pads or bedding, depending which regime is adopted; the liquid component of the animal waste can be irrigated onto the fields at any time and that solid component not used for culturing protein supplements could be ploughed in when convenient. Thus the original circle will be partially completed. There is the risk-spreading factor to be taken into account, too; a combined arable/livestock unit would be at less risk from rising feedstuff prices or downward variations in the prices of either sector of its produce. Offset against this would be the greater managerial difficulties of a double-sided unit.

Whatever solution or process is used, it is essential that it should not be too sophisticated. Like the position in sewage (see Chapter 5, page 109), agricultural engineers have taken the lead in suggesting solutions for the animal waste-from-intensive-unit-problem. Solutions on the lines of ordinary sewage disposal techniques are inordinately expensive (44); other examples of projects initated by chemical engineers include that postulated by Bery (1972 (45)), the U.S. Bureau of Mines (46), and various anaerobic-fermentation projects and "racetrack" digesters under pig pens - which flocculated so heavily that pigs in the pens above were suffocated (47). These projects were over-complicated and over-engineered; the engineer's contribution can be valuable, but not without the requisite biological information.

Summary and Conclusion.

It has been shown that animal "waste" has a sufficiently high N.P.K. economic value when applied to land to warrant its re-use in that direction and that no hygienic disposal process is warranted; but that processes, such as the separation of the solid and liquid components and the microbiological up-grading of the solid component do warrant investigation, to increase the efficiency of recycling.

Contrariwise, it has been shown that for the 3.57 million tons of surplus straw produced (say) in 1972, there are at present few outlets and a high cost in removing from the field if it is to be utilised.

The present main disposal method of burning, while relatively low-cost, is not entirely satisfactory from a biologist's point of view, since it wastes (in the pejorative sense of the word) half of a homogenous photosynthate; but economically, it does not impose sufficient external cost to warrant the total discontinuance of burning, except in certain sensitive areas. Alternative processes of disposal are unattractive. Any scheme for reclaiming straw would have to bear the entire process cost. However, the state of supply of cereals throughout the world at the present time is such that any proposal for utilising a higher proportion of the crop biomass is worth investigation.

It has also been shown that these waste problems have been caused by recent changes in farming practice; and a partial reversal of these changes could alleviate some of them.

Solutions to farm waste problems should not be over-complicated; in fact, they should be as simple as is commensurate with product quality, hygiene and other requirements, especially if they are to be installed on-farm.

This chapter has also illustrated some of the main points of the thesis, as developed in Chapters 1 to 3, regarding the recycling of low-value wastes in general. The possibilities opened-up by increasing scarcity of primary products - as in soya beans; the importance of institutional factors (e.g. the modern monoculture farm) and the problem of high transport costs of high-bulk wastes as an obstacle to reclamation are all good examples; but best of all, the movement of N.P.K. prices during the course of this work illustrates the basic unsoundness of planning the long-term on current information.

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(2) Okey, Rickles and Taylor, "Relative Economics of Disposal by Selected Wet and Dry Techniques," Cornell Conference on Animal Wastes, 1969. Cost per animal/year for "wet system" ranged from $97 per animal year for a 500-head herd down to $18 per animal year for a 25,000 head herd. The animals were beef cattle.

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(4) G. Borgstrom, in "Too Many" (Collier Books, N.Y. 1971, Macmillan, 1969), roughly estimated some 40 millions dependent on aid food in India alone.

(5) U.N. Population Estimates (High). Should be used with caution.

(6) Debate centres on the quantities of protein required to maintain health, which is disputed among various authorities.

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(9) First Report of the Royal Commission on Environmental Pollution, H.M.S.O. 1971. Cmnd. 4585, p.23, para.57.

(10) Wheatland and Borne, Institute for Water Pollution Control. Journal No. 2, 1970. Land required, 10.14 million acres: usable, 48 million acres.

(11) S.L. Willetts, "The Economics of Farm Waste Disposal", Surrey University, 1972.

(12) Communications from Haro Limited, 1971, and K. B. C. Jones, 1974.

(13) K. J. Seal, unpublished Ph.D. thesis, 1973, Aston University. Restricted access.

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(15) Willetts, op. cit. p.43.

(16) Willetts, op. cit. p.42.

(17) Farmers' Weekly, 22.10.1971. op. cit.

(18) K. B. C. Jones. Lecture delivered to Biodeterioration Society, 1.3.74.

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(27) Faygate and Babb, Journal of Dairy Science, 55(6), 870-72.

(29) L. W. Smith, H. K. Goering and C. H. Gordon, "Influence of Chemical Treatment on the Digestibility of Reminany Feces", and W. Brady Antony, "Cattle Manure: Re-use through Wastelage Feeding", Cornell, 1969.

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(31) the "Sunday Times" report, 22.3.74., where unscrupulous compounders and others have been making use of heavily pathogen-infected inadequately-prepared D.R.M. as a feed.

(32) Hoggetts, op. cit. p.23.

(33) Discussion point, Manchester Fermentation Conference, 26.3.74.

(34) Personal communication, Severn Valley River Authority. Some 5 prosecutions for escape of animal effluent to 40 escapes of silage effluent.

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(37) N.F.U. Working Party, op. cit., p.18. Table 6. "Farmer's Weekly", 28.2.72.

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(41) T. G. Barnes et al. International Biodetn. Bull. 8(3), p.112.

(42) For cannery etc. wastes, see A. B. Wheatland, "Characteristics and Methods of Treatment of Waste Waters from Crop Processing", presented to the East Midlands N.A.A.S., 1968. Also a Press account; "Sunday Times", 10.12.72. under heading "Freeze-for-all farm boom as food towns come to Britain", it describes how one farmer freezing his own produce was driven to use the services of a Scandinavian freezing firm because of effluent problems.

(43) Manchester Conference, op. cit.

(44) See (2) and (21) above.

(45) M. K. Bery, unpublished Ph.D. thesis, Aston University, 1972.

(46) H. R. Appell, Y.C.Fu., S. Friedman, P. M. Yarovsky, "Converting Organic Wastes to Oil", Agricultural Engineering, 53(3), March, 1972, pp.17-19. See sceptical economic evaluation by du Forest, ibid. p.20 and 'pyrolysis' section Chapter 4.

(47) Hoggetts, op. cit., p.18. ('Oxidation ditches'.)

CHAPTER 7: DISCUSSION OF POINTS RAISED.

The Relation between Technology and Economics as Disciplines.

In addition to demonstrating the applicability of various principles discussed in the first three chapters to the situations and projects discussed in Chapters 4, 5 and 6, this work as a whole, and the last three chapters in particular, has raised several issues, some of which can be discussed here and tentative conclusions drawn, and others of which will have to be dealt with in future work, perhaps by other researchers. One of these is the relation of economics to technology or any of the applied sciences. How can the economist and the technologist be of help to one another?

Much of that which is understood as 'economics' in technical publications and by scientists and technologists is really sophisticated cost-accountancy - involved in estimating the costs of installing and running newly-developed processes. Now technologists generally are numerat, in most cases as numerate as the average economist, if not more so; they are quite capable of grasping the principles of costing; given the necessary initial advice and do not need the services of a professional economist. (Perhaps the services of a cost-accountant may be needed initially).

For the economist to be useful, he must do something more than cost the operation. Not that costing the operation is not useful; it is vital in order to compare the merits of rival processes and to assess the viability of a particular scheme; but the costs of a proposed process are only half the information. The process or technology has to be set against its economic background.

(i) Will the product find a market? (i.e. will it supply an un-met want or will it supplement or replace an existing product?)

(ii) What sort of input (in capital, labour and raw material) will the plant require?

(iii) In the cost of a process using a waste product, what quantities will be available and at what cost?

(iv) Will these conditions obtain at the end of the lead-time for the development of the project, or will there be a change in conditions such as a change in the status of a waste product, as has happened with newsprint waste?

(v) Is the potential demand for the product of a similar order to the potential supply?

If the supply is of a very much smaller order of magnitude than the demand, then it will suffer all the disadvantages of a marginal product, here defined economically as a product whose quantity is too small a proportion of total supply to affect the price. If the quantity is too large in relation to the supply, then the process will never offer more than a partial uptake of the waste, which is a grave disadvantage, bearing in mind the inelasticity of the supply of waste materials. Alternative provision may have to be made and the cost of a double provision of facilities may be prohibitive. (Vide town-waste composting). These are the kind of questions that have to be asked.

For these reasons, the place of an economist as an auxiliary to a research project is at the beginning of a project, to help the technologist(s) decide whether or not to embark on a project or not; to help him (or them) decide on which of several possible choices of direction the research is to take and to advise on which criteria to aim for, if the research is to aim at a product; and at the end of the project, when it has reached pilot-plant stage, or is about to be transferred to the pilot-plant stage. Then, in the light of up-dated information, the economist can advise the research team on whether to continue to the production stage or not, some cost data being then available. During the laboratory stage, the difficulties of scaling-up to gain cost-data are such that the economist's role is limited to updating his own initial information. The project will then stand or fall purely on its technological merits.

In the case of the present set of projects, the direction of investigation was indicated by the problem of a temporary surplus of waste paper in 1970, a more permanent surplus of straw and a system-induced surplus of farm-animal waste - plus the reasonable probability of a future shortage of certain biosphere materials, especially foodstuffs; that much was deduced by the author's microbiologist colleagues. It was also pro-indicated by the low expected cost of microbiological protein compared with that from other sources; as given in much other published material; and by the simple fact that their discipline dictated the technologies to be investigated. For various reasons, including lack of finance, investigations were not taken as far as we would have liked; Barnes' work on the conversion of waste paper (1) was not carried as far as a feeding-trial on reminants, for example, although, as seen from Chapter 4, it was already known from other work elsewhere that ruminants could metabolize unconverted newsprint; trials on mice proved inconclusive, as it was found that mice were unable to maintain themselves either on the fungal product or on unconverted newsprint. It should be noted, however, also from Chapter 4 that the original project - composting of town refuse - was eliminated at a very early stage. Thus it cannot be said that the benefit of having an economist on the team was fully reaped, in this case.

However, it has been beneficial in that the technologists involved have perhaps become a little more aware of the economic sphere than would have otherwise been the case.

The Relation between Economics and the Subject Matter.

On the whole, the contribution of the discipline of economics to the problems of waste recycling and disposal and their elucidation has not been impressive. The work of Mishan, Boulding, Kneese, d'Arge and others has been mentioned; but, before about 1965, serious economic writing on waste problems was practically non-existent and even now is not very plentiful. Resource problems, of course, have attracted economists' attention since Malthus' time; the reconciliation of what was seen as potentially unlimited demand with restricted supply has always been one of the bases, if not the basis; but in the present environment-cum-resource crisis, the practitioners of other disciplines, notably biology, have taken the lead in raising the issues involved and the economists have followed.

In part this was due to the natural scientists' experiencing the phenomenon of negative spillover at first-hand, via their own observations; economists dependent on 'desk' material - written data of all sorts - would not always be in sufficient contact with the physical world to realize what was happening. Indeed, if an economist relied on normally-generated data or even, often, his own compilations, he would never take the lead on this problem; such data is only collected if there is a demand for it. The relatively few economists who did take a lead were motivated by other than economic data - scientists' observations or a general sense that there was something wrong with society as they observed it.

In equally large part, however, this was due to some of the present faults of economics as a discipline. Economics is a specialized branch of behavioural studies dealing with the behaviour of large aggregates engaged in a special activity - supplying their material wants. As such, it lends itself more easily than the other social sciences to quantification; but unlike the natural sciences, the entities represented by the algebraical symbols are more often abstractions and concepts rather than real quantities. Furthermore, attempts to construct theories on such abstractions often lead to divergencies between economic theory and the real world, which persist far longer than any equivalent in the natural sciences; the natural scientist can always check his assumptions by experiment or observation. Thus there are three relevant weaknesses in economics; incompleteness, a tendency to spurious accuracy and a tendency for theory to diverge from practice. The first factor, incompleteness, deserves some enlargement. As a brach of a behavioural science, the course of economic events depends very much on the psychology of the people in the institutions involved; current economics is very much impinged-upon by past events and many economic phenomena can only be explained by historical causation. Much economics is determined by social organization, just as economic factors determine the shape of much social organization; but economic factors do not dictate the whole of social organisation. These are examples showing the incompleteness of much modern economics.

An example of how even basic economic theory can diverge from practice, with regard to the present subjects of discussion, it should have been reasonably obvious since Veblen (2) that there are four factors of production; land (including all subterranean resources, climatic factors and the genetic endowment of the people), labour, physical capital (including liquid assets) and mental capital - the last meaning the various skills, technologies and accumulated know-how available to a society - not the classical three; and the economics of growth, innovation, technology, resources and the disposal of waste are far easier to understand if mental capital is considered as a separate factor of production. 'Mental capital' includes entrepreneurial as well as technical know-how.

As has emerged during the specific discussions on various forms of waste, many of these wastes have been created by technological developments as much as by purely economic factors. The problem of surplus straw has arisen because of the advent of the combine harvester and the availability of artificial fertilisers making possible specialisation in arable farming - see Chapter 6. The proportion in paper has risen because of changes in the technology of the marketing of consumer-goods which involve more packaging material; see Chapter 5. On the other hand, even before the discovery of gas in the North Sea, the proportion of ash and cinder in town refuse was falling, partly due to the evolution of a range of gas fires, gas (and oil) central heating systems for private houses and electric heaters that were more thermally efficient than their

Predecessors and thus reduced the costs of using these convenient but comparatively expensive fuels to the point where they became competitive with solid fuel. The creation of waste products is determined by the level of economic activity as far as quantity goes, but is qualitatively determined by the kinds of technology in use and by how much each is significant. The diminution of the escape of waste products into the environment in such a manner as to cause pollution or to impose a cost for its disposal will, therefore, depend largely on which technologies are available to diminish the waste, or to re-use it. It follows, then, that zero economic growth is no answer to waste and pollution problems. On the contrary, only further accumulations of 'mental capital', and therefore an increase in the resources of the economy and hence resource-intensive economic growth will ensure that any waste-accumulations and pollution problems are solved and present and future recycling schemes made feasible.

Data collection has already been alluded to, bottom of page 159. As will have emerged during the chapters on specific wastes, the state of data collection on wastes in general and disposal costs in particular is not one that can be considered good. Unless governments, researchers, local authorities and firms have access to a ready supply of data, it will not be possible to do very much serious economic work on the subject. Under the new structure of local government in England and Wales, responsibility for refuse collection and disposal has been divided - collection to the district authorities, disposal to the counties. This may not make for administrative efficiency, but at least, with two different budgets involved, it may be easier to procure reliable disposal costs. The form of accounts under the old dispensation made it very difficult for many authorities to break out a disposal cost (3), and much costing in this field was extremely sketchy. Reasonable estimates are obtainable for animal wastes, but these tend to be based on averages, with mean deviations of up to 15% in either direction, depending on the feeding regime and other factors, and the figures published by the Department of Agriculture for straw are based on samples which have been strongly queried by the N.F.U. In the present state of data, the recent decision to re-commence publication of the Refuse Disposal Costing Returns is to be welcomed.

Final Points.

There are a few final points to be made in this general section. Firstly, is it possible to find an alternative to the "herring-spawn" principle in technological invention, in order to reduce the time and effort required to produce a genuine technological innovation in this field? Perhaps not; the task of the economist here is to prevent too many unviable spawn from developing to too late a stage and eating an unnecessary quantity of resources. However, under present arrangements, industrial secrecy may hamper the comparison of projects developed by different institutions; for example, it is known that the Wolfson Laboratories at Cardiff are doing similar work to Aston, but considerations of industrial secrecy prevented them from supplying much suitable information to the author (4).

Scientific over-specialisation is also a hindrance to work in the field of waste-recycling; in an area where there is no one best solution, waste reclamation is very much a multidisciplinary activity. Yet, the author has had occasion to expand on engineers' solutions (very prone to over-designing), chemists' solutions and, the main part of this work, microbiologists' solutions. Ideally, a range of solutions could be produced by the co-operation of many different technological disciplines for economic evaluation. However, it must be said that despite the possible limitations of product range and quality by the characteristics of the micro-organisms involved, microbiological solutions to the problems of re-using biosphere wastes appear encouraging. As detailed above, there is no need for complex capital equipment and the low operating temperatures and pressures promise a cost curve with a comparatively low break-even point, thus rendering the solid-substrate processes, especially, amenable to small-scale application.

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CHAPTER 8: SUMMARY AND CONCLUSIONS.

Summary.

In Chapter 1, the thesis was introduced and placed in its historical setting - important, because this work cannot be expected to remain valid for all time; it must be seen in the context of its own time. Appendix B will enlarge on one particular aspect of its historical background, relating to the general disillusionment with economic progress which set in in the late nineteen-sixties. A definition of "waste" was attempted; or rather, several possible definitions were explored. It was decided that while a waste was a production by-product with no utility either to the generator or to a potential user, a hard-and-fast definition was to be avoided, in view of the numerous understood meanings of the word "waste". Economic and biological cycles were also examined, especially the well-known carbon cycle; and in this connection it is important to stress the difference between the amount of carbon held in the total biosphere (as against that in the primary reservoirs) and the amount of material held in economically useful vegetation; by making part-use of some of that vegetation that is not economically useful at present, that category of material will be increased in proportion. An energy gloss was included; but since the prime function of this work was not to discuss energy, no great detail was given. It will have emerged from subsequent chapters, however, that biosphere wastes do not constitute an alternative energy source of any significance. Their calorific value/unit weight is comparatively low, and their quantities of arising are too small for them to make a significant contribution to energy supply. Moreover, the heterogenous character (in the case of the mixed waste) and the fact that most of them are solid lead to handling problems that create additional costs above those of fluid fuels. In the conclusion to that chapter, emphasis was placed on re-introducing material into a portion of the natural cycle where it will be of use.

In Chapter 2, the global economic aspects of materials supply were discussed; the main feature that was introduced was the importance of the Ricardian rent factor, underplayed by many economists in this field. This rent will increase hyperbolically over time with the exhaustion of a non-renewable resource, and exponentially over time with a renewable resource producing at maximum continuous output, if demand rises. For obvious reasons, this trend may be masked by short-term changes in the rate of demand or the period of working may be increased by substitution; but this feature of increasing rent may be more important in deciding whether new, land- or resource-saving technologies may be developed or not, than any problem of the absolute exhaustion of supplies. At present, and contrary to the assumptions made in many "doomsday" writings, a complete inventory of the earth's resources has not been made and unquestionably many discoveries of raw-material supplies lie ahead; an approximate inventory may soon be made with the help of recently-developed surveying technology such as earth-resource satellites, geo-magnetic measurements, and photography at various wavelengths other than the visual spectrum; but the prospect of disturbance of the rent-trend through new discoveries still remains; but owing to the nature of exponentially-growing demand, the rightward disturbance of the hyperbola may not be large. If, at an exponential rate of increase in consumption of petroleum, of 8.8%, the reserves known in 1970 and proved were to be exhausted in 19 years, an amount representing double those reserves would be consumed in a further five years. These figures are not intended to portray a real situation, but as examples.

Two suggestions were made to overcome the defects of rent as a method of conserving resources - an ad quantitatem tax, to encourage the establishment of resource-saving technology and to discourage extravagant consumption; during the early low-rent phase and a "long-term forward" market in various primary commodities with the object of raising present 'spot' and short-term prices and to gauge price levels far enough in advance to determine the investment and technologies that will be needed to overcome anticipated scarcities and rent factors at that time.

In Chapter 3, the micro-economic factors governing recycling of biosphere wastes were discussed; and the all-important rule of non-mixing of wastes (not including pre-determined combinations of wastes to manufacture a final produce), was introduced. Institutional factors and other obstacles to recycling were discussed; in particular, the effect of varying demand due to trade-cycle factors on a marginal waste where the material was recycled back to the original use was discussed, using an 'open-loop' model. The importance of timing in the introduction of new technologies was discussed in both Chapters 2 and 3, and will be further discussed in the 'conclusion' section below. The question of finding an alternative basis for discounting future income and expenditure to current interest rates was also discussed and again will be mentioned below.

Chapters 4, 5 and 6 partially demonstrated the principles introduced in the first three chapters, with application to town waste, sewage and farm waste respectively, but were also examinations of the work of the author's colleagues at the University of Aston and of other projects as well. In particular, all three chapters demonstrated the importance of the principle of non-mixing of wastes, the importance of separation and the need to assess any recycling or disposal project on long-term rather than current-price factors; but each waste had its own economic characteristics.

Straw is relatively homogenous, but its collection from the field incurs high opportunity-costs. Farm mammalian waste has lower opportunity costs, but for best use requires separation into its solid and liquid fractions. Work is proceeding at the University of Aston Biodeterioration Information Centre (1974) on the possibility of stripping the nitrogen from the liquid fraction of animal wastes with calcium oxide (obtainable as a virtual waste product from the cement industry), the nitrogen being driven off as ammonia, which can then be applied as a nitrogen fertiliser, while the lime precipitate, which contains other nutrients derived from the waste, can be applied as a conditioner for acid soils; the principle is promising, but one obstacle may be the lack of a patentable factor in this very simple technology - another institutional obstacle. Household refuse has little collection opportunity costs, but in agreement with the Local Government O.R.U. (1) and other authorities, it has been concluded that in the absence of any efficient technology of separation, the most feasible way of recovering the non-metallic portion of this waste is by separated collection; the extremely heterogenous nature of present refuse drastically limits the range of end-product available and also limits quality at a low level. Sewage was included mainly for completeness; the problems here appear to be extreme dilution of the material, small overall quantity and contamination by toxic industrial wastes and the run-off from road drains. It, too, has little opportunity cost, as most systems concentrate the sewage flow at one point or a small number of points. However, as has been shown, even separated collections need not be inordinately costly; and, as has probably not been shown so clearly, it may be possible to reduce handling and transport costs, e.g. by using larger bales for straw and paying some attention to the design of vehicles for separate collections. (At present Worthing uses conventional refuse collection vehicles, with wire-mesh-sided trailers for separated items).

Transport costs, however, may remain high for the crude waste in all cases. Except in some special cases, where bulk industrial arisings or collected household refuse can be transported by rail economically, the only feasible method of conveying these wastes at present is by road motor transport, a relatively labour-intensive form of haulage. Specialist forms of conveyance such as air or water pipelines may be ruled out, for all practical purposes; the social/environmental cost of refuse-collection vehicles is not large, compared to other categories of road traffic (2), and the capital costs of the alternatives are very high. This confirms the earlier paragraph in Chapter 3 and the costing of straw transport in Chapter 6.

Institutional factors have also been shown to be important in all three cases, but particularly where the public sector was involved. In the farm sector, the primary institutional factor is the existence of the specialist intensive unit.

Finally, Chapter 7 raised general questions arising out of this work, especially those relating to the relation between technology and economics.

Conclusion and suggestions for Further Investigation.

To head this section "Conclusion" would seem to be presumptuous in view of the on-going nature of work in this field, but all works have to be concluded at some point.

(i) It can be concluded that, owing to rising population in the world as a whole and rising material expectations in that population - not to mention the admitted need to raise the standard of living of the poorest to a tolerable level, the pressure of demand for primary resources, and hence the rent-element in their price, will rise;

(ii) that owing to the above, the development of technologies that utilize wastes as a resource, and hence are 'land-saving' is a present imperative to alleviate or prevent future shortages. This includes especially, biosphere resources which are very often under pressure, not only for the material which they can supply, but also for the land which they occupy in many instances.

(iii) It is important that such technologies should be available when wanted, not too prematurely and not so far after the event as to result in avoidable scarcities;

(iv) it is important that as far as possible, wastes should be kept separate prior to re-use or disposal;

(v) any scheme should be thoroughly evaluated before full installation is attempted, preferably at pilot stage. Some schemes especially in municipal composting have proved costly failures when this was not done.

(vi) With some of the type of waste that we have been discussing, hygienic disposal may be the only practicable strategy. Possible end-products have to be considered, in relation to the waste content, before recycling is considered.

(vii) Notwithstanding (vi) above, the range of possible products has to be widened as far as possible. Marketing institutions in waste may have to be strengthened in order that knowledge of potential markets be widened; new technologies, or adaptations of existing technology, will be needed in order to relieve the dependence of those wastes that are recycled back into their own primary streams on a very unstable cycle, as well as to enable the re-use of other wastes.

(viii) New technologies need not necessarily be elaborate or highly capital-intensive (so-called 'high' technology). Indeed, within the limitation of product, one of the virtues of microbiological technologies is that, in comparison with many chemical technologies, they need be neither.

It was not possible to finally conclude that the University of Aston projects were viable, although for simplicity of operation, amenability to small-scale operation and comparatively low capital cost it shows promise. Reservations must lie on product quality and use under farm conditions, in the case of a farm process; product quality and procurement prices for newsprint in a paper-recycling process, though less amenable, varieties of paper may still make an economically feasible input.

Some suggestions for further investigation are given below:

(a) Technological.

Separation technology, for waste arising from manufactures (much work already in progress, especially from the Warren Springs Laboratory), since these wastes arise intermixed. Automobile wastes have attracted the most public attention, but the Battelle Institute have investigated the problem and there are many others; perhaps intermixtures of plastics and paper arising from packaging, would be most relevant here. Also further investigations of the prospects for and limitations of microbiological bio-regradation technology would be needed. As written above, further technologies for the re-use of these wastes are needed.

(b) Economic.

The actual operations of the rent-effect in the cases of renewable and non-renewable resources; investigations for finding a sounder basis than current interest rates on which to base cash-flow and other discounts, possibly based on probability; the possibilities of institutional innovations such as those suggested in Chapters 1-3 (long-term forward markets? Waste "brokerage"); and further evaluations of any technologies that may be suggested, particularly from the more idealistic parts of the technological community. Also an examination whether the basic assumption of economics, that wants for material goods and services are potentially infinite, although demand for any one good (e.g. a foodstuff) may be finite, holds good in all circumstances.

This is not an exhaustive list; anyone embarking on this field will discover more.

References.

(1) Personal Communication, Mr. Roberts, L.G.O.R.U., Reading.

(2) See the First Report of the Standing Committee on Research into Refuse Collection, Storage and Disposal. Department of the Environment, 1973. pp. 38-40.

APPENDIX A: PYROLYSIS COSTS.

With reference to the relevant section in Chapter 4, this is a statement of the manufacturers' claimed costs for two pyrolysis processes developed for the purpose of producting 'oil' as an end-product and their adaptation to U.K. conditions.

Both processes are American; and it will be seen immediately that conditions differ so far on this side of the Atlantic that North American technologies are not necessarily applicable. The organic fractions of continental European refuse are of the same order of magnitude as British refuse, taking absolute weights as the yardstick. Total refuse generation per head per day (including some trade refuse) is some 6 lbs; the British equivalent is 2 lbs or less; in some areas as low as 1.74 lbs. American annual paper consumption is twice the British per capita average and there is, on average, less ash or cinder than in British refuse. Interest rates are also higher in Britain; and since pyrolysis is highly capital-intensive, this could be critical in affecting 'profitability' or opportunity cost and whether the process is chosen. Two British processes are also discussed; they show promise of being less capital intensive, but in one case, the British Steel Corporation process, this is achieved by using obsolete blast furnaces, thus eliminating most of the opportunity-cost from the capital budget.

Furthermore, it must be remembered, that with used newsprint at present fetching relatively high prices - £22 per ton (October 1974) - and finished paper, as supplied to publishers, for use in paper-back books is commanding prices of £200-£300 per ton - the opportunity cost of converting refuse into energy is very high; and it has already been shown that refuse can only supply a very small proportion of energy demand. Pyrolysis should be seen as a process for producing a substitute petro-chemical feedstock, possibly for plastics manufacture, rather than as a process for supplying portable energy.

Costs of Schemes.

(i) Garrett Research and Development Co. Inc.

This is a scheme of 'conventional' character, designed to produce 1.1. bbl. of 'oil' from 1 ton of crude refuse, also producing gas, a carbon char and a residue of metallic scrap and other inert material. The metal is recovered in a better condition than would be the case with incineration. The object of the scheme was to produce a low-sulphur oil, with regard to the short-term American fuel crisis of 1972-4 and to current air-pollution legislation. There was, and is, a strong political demand in the U.S. that it should remain self-sufficient in energy.

	U.S. conditions	British conditions
Break-even throughput	2000 short tons/day.	
Depreciation life	25 years.	
Population served	600,000	1,800,000
Cost (excl. land-1971 values)	$12 mn.	$5 mn.
Interest rate	6%	9½%*
Capital Charge p.a.	$955,000 (£397,000)	£529,000
Total ann. cost/ton.	$5 (£2.08)	£2.55
Revenue @ $4 * bbl./ton.	$4.4	£1.83

*At present, Middle-East crude prices range up to $17-$18 per barrel, but owing to the lower quality of this 'oil' a downward adjustment must be made in probable price to about $13 per barrel, or an income of about £5-£6 per ton. This will be partially offset by current interest rates at 12½% or more; and would have to be compared with at least equivalent prices that could be obtained by the separated collection of the paper component of waste, for recovery as material.

(ii) U.S. Bureau of Mines System.

An even more capital-intensive scheme, designed alternatively to pyrolise refuse in the presence of sodium carbonate catalyst at pressures of approx. 4500 psig. and at temperatures of 1200 C., or to pyrolise cattle waste, without addition of catalyst (since cattle waste contains potassium carbonate) at the same parameters of pressure and temperature. The oil yield is raised to 2 bbl./ton (short) of crude refuse and the American break-even input falls to 900 short tons/day; still equivalent to a British or European town of, say, 900,000 population as opposed to an American one of 300,000. There have also been technical problems in finding refractory materials that will resist the attack of hot sodium carbonate. Capital cost in March 1972 at the 900 U.S. t.p.d. level was estimated at $20 million; and one feature of the costing which would not apply in the U.K. or in any other country where refuse disposal is a public responsibility is that it was anticipated that disposing authorities would be charged $5 per ton of refuse disposed; and their costing was defective in that only operating costs were covered. As a method of using farm waste, of course, it is not practicable.

(iii) Warren Springs Process.

An elegant British process, which simply involves passing dried and compressed refuse down the centre of an induction coil. The coil induces currents in the metallic fraction of the refuse, which heats it up and causes it to gasify.

Ingress of air is prevented by the compressed input refuse. 'Oil', gases and a metallic residue are produced; and the method overcomes the difficulty of locally heating a material of such low conductivity and calorific value. Since the value of the 'crude' is quite low, oil sales are considered of less importance than metals recovery. At pilot plant stage, 1971; is capable of being operated on a reasonably small scale and industrial uses come to mind.

(iv) British Steel Corporation Process.

Concerned with metal recovery, this process uses obsolete metal furnaces that have still some residual physical life. The organic and inorganic fractions are separated, using air elutriation or other processes depending on the heavier specific gravities of metallic objects; the organic portion is then gasified in a retort, and the gases, 'oil' and char used to melt the metals in the adapted furnace, producing a metallic mix and a usable slag. Very much an adaptation of conventional metal-melting, using refuse instead of coal, its advantage is that it uses the residual lifetimes of equipment that would otherwise be scrapped as being on too small a scale for modern technology; one snag, of course, would be that the supply of obsolete steel works is by no means evenly distributed geographically. Work on similar lines is also proceeding in the U.S.A.

APPENDIX B: THE "GAUTAMA EFFECT", OR THE DIMINISHING MARGINAL UTILITY OF CONSUMPTION.

It will be recalled that in Chapter 1 mention was made of the "second generation of affluence", and the revolt against consumerism, which provided much of the impetus behind the environmentalist movements of the late nineteen-sixties. This appendix will give a fuller explanation of the phenomenon. The title, "Gautama effect", was chosen because Gautama (Buddha) was the chief exemplar of the injunction preached by all the major religions, not just Buddhism, to their more affluent followers to "sell all you have and give to the poor"; chief, because he was a king's son who gave up wealth and privilege in favour of seeking enlightenment and founded a religion. The Christian tradition, of course, had many examples; St. Anthony, the founder of Christian monasticism; St. Francis of Assissi, who was the son of a rich cloth merchant. However, with the end of the Middle Ages, the Christian mystical and monastic tradition petered out; or became fossilised. The religious orders decayed from within before first the Reformation and then the Enlightenment attacked them from without; and the West was left without a usable mystic tradition. It was very noticeable that the hippies of the late nineteen-sixties turned to the Indian subcontinent for inspiration.

In pre-industrial society, however, the fewness of the rich meant that those who did turn their back on wealth were a tiny minority of the society as a whole; however, this modern movement which questions high consumption is a mass movement, which is not surprising when the mass is comfortably off. It not only finds its expression among hippies and drop-outs, but also with growing resistance to consumerism, the barrage of criticism which the motor industry has been subjected as the symbol of all that is bad in modern industrial society (boring assembly-line working, 'planned obsolescence', shoddy quality, 'creating more desire' for the product by high-pressure advertising, and the negative spill-over from the mass use of cars, etc) and the efforts of several thinking people to find an alternative. Here is a possible explanation.

Let u be the objective utility of a given consumption level of consumer goods Q_o, including intangible satisfactions; we can assume that the rate of increase of marginal utility, d_2u/dQ^2 is negative. As the stock of consumer-goods available to the consumer increases the marginal utility decreases until the optimum consumption point is reached, where $du/dQ = 0$; the level of consumption here we can call Q_1. If consumption continues beyond this point, u(Q) declines; the point Q_2, where $u = 0$ is reached. Beyond this point Q_2, u is negative and the "bellyache zone" has been reached.

All this would be simple, but for the fact that here economics and psychology meet; there is no mechanism for ensuring that consumption stays at any one point, Q_1 or even Q_2. The values of u, Q_1 and Q_2 vary with the circumstances of each individual; and beyond these objective variations, there is a <u>subjective</u> utility, which we can call u_s, which is dictated by the psychological and social state of the individual. Now, the desire of the individual is to reach the point where $du_s/dQ = 0$; where he feels himself to be satisfied. By definition, almost all the time, this point is greater in terms of Q than Q_o and can be greater than Q_1 or Q_2.

Now, for a reasonably-adjusted consumption, u_s will become close to u; but there is no guarantee that consumption will be balanced. In real cases of imbalance, the rate of increase in subjective utility, d_2u_s/dQ^2 may very well be positive - in other words, the more the consumer consumes, the more he wants in increasing quantities. Consumption is free to increase beyond the level Q_2 into the bellyache zone; and beyond. The extreme case, of course, is that of an addictive good such as heroin or alcohol (for an alcoholic); the consumer may drink or drug himself to death. In less extreme cases, where d_2u_s/dQ^2 is negative but greater than d_2u/dQ^2, the individual's level of consumption may lead him to consume beyond the "bellyache point" Q_2, where a negative feedback (bellyache, hangover, unhealthy financial position) causes him to reduce consumption and subjective utility nearer to actuality. In between are those situations where social or psychological pressures cause over-consumption; the social drinker afraid to pass a round for fear of losing face; the maintenance of status in all forms; the many well-documented cases of people attempting to compensate for deprived childhoods; and, above all, the propensity of the whole of Western society to over-consume, for the sum of these and other reasons. Up to now, the examples given have been single consumption goods; it is when the whole body of consumption goods enters the realm of declining subjective marginal utilities that a 'Gautama effect' on a large scale takes effect.

Two Generations.

One of the founding assumptions of economics since Adam Smith is that while the supply of goods is finite, demand is potentially infinite. That observation holds good as long as:

(i) in an economy where the distribution of capital and income is unequal and the lower-income groups in society have an unsatisfied demand for either biological necessities (food in extreme cases, housing of a standard considered adequate, basic clothing), culturally-determined necessities (those goods which are necessary for an individual to function in society, which may range as high as the ownership of a car in North America and Australasia) or even luxuries, that demand is ineffective through lack of purchasing power; alternatively,

(ii) in a society with a rather higher per capita income, where the demands for biological necessities have been met, and income is still unequal, there is still an unsatisfied demand for certain cultural necessities and for status-symbol luxuries enjoyed by the more privileged classes; and

(iii) there are no legal or conventional caste barriers in either case that prevent the lower classes from aspiring to the needed or desired goods, or there are no technical impossibilities of widening ownership (e.g. there will never be enough country estates to go round). To put it shortly, demand is made up partly of necessity, partly of desire; and, when necessities have been satisfied, it is the culturally or psychologically-generated demands that give the impression of an infinite aggregate demand.

This culturally-generated demand will vary with the kind of society and the technology available. At one extreme, the cultural demand of nomadic hunter-gatherers may be limited to whatever can be transported on a man's or animal's back; at the other extreme, as in modern Western society, it is limited only by the range of consumption goods available and the extent to which the general desire for these goods can be awakened. ("Create more desire!") This in turn depends partly on the rate of technological innovation - which extends the range of 'services obtainable from goods' - and partly on the range of psychological pressures that can be brought on consumers. It may be argued, of course, that advertising on behalf of one line of branded goods may be cancelled out by advertising on behalf of its competitors; but the total effect of advertising, in the short run at least, will be tostimulate desire and demand over the whole range of consumer goods. In modern Western society, and especially in North America, consumption, especially of necessities, is not limited by lack of earnings, pockets of poverty apart.

One of these psychological factors that can be used is the 'deprived-child' effect; people brought up in the poverty of the depression or wartime austerity would be more likely to be affected by such demand stimulation than a generation born into affluence, since the 'deprived-child' effect is the process whereby people seek to compensate for both the physical and psychological deprivations of a poor childhood by high consumption. This would account for the timing of the reation against high-consumption by Western youth - starting around 1964-5. Another is the 'new toy' effect of owning a novelty; this would be in addition to the objective utility of a new line of consumer good. Sex-linked and status-linked stimulations, of course, are commonplace in consumer-good promotion.

However, if the Maslow theory of a hierarchy of needs is accepted, it follows that once the basic needs of biological necessity and social necessity (including sexual desires) are met, other needs supervene. Maslow refers to them as 'metaneeds', the needs for higher forms of experience; for intellectual stimulation, for creative expression, for 'spiritual' experience; and basically, it is the attempt to satisfy these needs by the consumption of food, sex, material goods of all kinds, that drives subjective utilities upwards and consumption into the negative-utility "bellyache zone". Now a feature of Western society as a whole has been a lack of satisfaction of these higher needs; and hence the whole society has moved into the negative feedback zone; this development has been helped by the long-term decline of Christianity and the inability of the established churches to provide for these needs. Now the burden of the teaching of the main religions not to pile up treasures on earth and to renounce the accumulation of consumption goods is that it is futile in the long term to try to satisfy higher needs with lower satiants; and that is what the West is learning the hard way. Given this, it is not surprising that the psychological stimulation of consumer demand is subject to diminishing returns. As consumption of material goods fails to satisfy higher needs, a negative feedback is built up; on an economy-wide basis, this is expressed with a general disillusionment with consumer-goods industries, with the whole consumer ethic and a questioning of its values.

The act of consumption creates waste, and the negative spillovers from wastes; increase with consumption to create another negative feedback. Certain types of consumption -

mass use of cars, for example, - create their own negative spillover, besides exhaust fumes. Disillusionment spreads further.

The consumer-goods industries themselves feel the consequences of that disillusionment; in falling public esteem, slackening demand growth and labour troubles. Furthermore, since, with the exception of electronics-based goods, they have run out of technology, they resort to gimmickry, which does not improve the position.

However, it is noticeable that the demand for more intangible goods such as education and interest in 'religious' questions is increasing. If interest in traditional Christianity is declining, interest in such quasi-religious fields as the occult, UFO's, and parapsychology has never been higher. Whether this trend continues through the present crisis will bear watching.

APPENDIX C: PUBLICATIONS NOT MENTIONED IN THE TEXT.

The purpose of this appendix is to give the reader a guide to introductory works and other publications, especially those not mentioned in the chapter reference lists.

Introductory Works: Environmental Issues.

For the 'lay' reader, and for the first-year student, there are still surprisingly few reliable initial books on the economics of the environment. On the whole, journalistic accounts are of little or no value; examples are often quoted at random and when any level of analysis exists, it is superficial and incorrect. Examples are the works of J. Aldous, ("Battle for the Environment", Fontana, 1972) Gordon Rattray Taylor and Alvin Toffler ("Future Shock", Bodley Head 1970/Pan 1971; ISBN 0 230 02861 8). However, some of the alarm-raising publications of the mid-sixties, written by natural scientists, are still worth reading as a background for Chapter 1. Examples are Rene Dumont, "The Hungry Future", (the author is an agronomist with experience of the mal-administration of agricultural projects in Africa and elsewhere in the Third World) and of course, Rachel Carter's "Silent Spring". Also worth reading are those economists who reacted against the growth at any price school; Mishan and Boulding have already been mentioned, but, in support of the argument in Appendix B, Charles Carter ("Wealth", C. A. Watts 1968/Pelican 1971) (ISBN 0 14 02 1346 5) should be read as one of many who questioned the pursuit of economic growth and the accumulation of material possessions for their own sake.

Introductory textbooks are still rare. Three are listed below:

(i) Peter A. Victor, "Economics of Pollution". Macmillan, 1972. One of the Macmillan Studies in Economics; SBN 333 13618 7. Good, but does not mention that compiling input-output analyses for even a city region takes time!

(ii) Paul W. Barkley and Donald W. Secker, "Economic Growth and Environmental Decay", Harcourt-Brace-Jovanovich, New York, 1972. SBN 0 15 51795 3. A clear and well-illustrated textbook.

(iii) D. A. L. Auld, (ed.) "Economic Thinking and Pollution Problems". University of Toronto Press, 1972; ISBN 0 8020 1767 3. Mediocre, with a tendency to make blinding mathematical statements of the obvious. Contributions include an apologia for the paper industry and a summary of impending legislation by Ontario province to reduce water pollution.

<u>More Advanced Work</u>.

While quite a number of articles have been published, advanced books on environmental economics are still few and far between; two good examples are:

(i) Peter Bohm and Allen V. Kneese (ed), "The Economics of Environment: Papers from Four Nations", (Macmillan, 1971; SBN 333 1327 6 9). Reprints from the <u>Swedish Journal</u> of <u>Economics</u>, v. 73, No. 1).

(ii) Allen V. Kneese, (ed), "The Economics of Environment; a Materials Balance Approach", Resources for the Future, 1971.