Waste Treatment and Disposal

Second Edition

PAUL T. WILLIAMS
Professor of Environmental Engineering
The University of Leeds, UK

John Wiley & Sons, Ltd
Waste Treatment and Disposal
Waste Treatment and Disposal
Second Edition

PAUL T. WILLIAMS
Professor of Environmental Engineering
The University of Leeds, UK

John Wiley & Sons, Ltd
This book is dedicated with lots of love to Lesley, Christopher, Simon and Nicola
Contents

Preface ix

Chapter 1: Introduction 1
1.1 History of Waste Treatment and Disposal 1
1.2 European Union Waste Management Policy 5
1.3 Waste Strategy of the European Union 8
1.4 Policy Instruments 13
1.5 EU Waste Management Legislation 15
1.6 The Economics of Waste Management 38
1.7 Options for Waste Treatment and Disposal 49

Chapter 2: Waste 63
2.1 Definitions of Waste 63
2.2 Waste Arisings 66
2.3 Municipal Solid Waste (MSW) 74
2.4 Hazardous Waste 93
2.5 Sewage Sludge 104
2.6 Other Wastes 110
2.7 Waste Containers, Collection Systems and Transport 119

Chapter 3: Waste Recycling 127
3.1 Introduction 127
3.2 Waste Recycling 130
3.3 Examples of Waste Recycling 143
3.4 Economic Considerations 159
3.5 Life Cycle Analysis of Materials Recycling 162
Chapter 4: Waste Landfill

4.1 Introduction 171
4.2 EC Waste Landfill Directive 174
4.3 Site Selection and Assessment 180
4.4 Considerations for Landfills 181
4.5 Types of Waste Landfilled 184
4.6 Landfill Design and Engineering 185
4.7 Landfill Liner Materials 187
4.8 Landfill Liner Systems 192
4.9 Processes Operating in Waste Landfills 197
4.10 Other Landfill Design Types 207
4.11 Landfill Gas 212
4.12 Landfill Leachate 220
4.13 Landfill Capping 227
4.14 Landfill Site Completion and Restoration 227
4.15 Energy Recovery from Landfill Gas 230
4.16 Old Landfill Sites 236

Chapter 5: Waste Incineration 245

5.1 Introduction 245
5.2 EC Waste Incineration Directive 248
5.3 Incineration Systems 251

Chapter 6: Other Waste Treatment Technologies: Pyrolysis, Gasification, Combined Pyrolysis–Gasification, Composting, Anaerobic Digestion 325

6.1 Introduction 325
6.2 Pyrolysis 326
6.3 Gasification 337
6.4 Combined Pyrolysis–Gasification 342
6.5 Composting 346
6.6 Anaerobic Digestion 357

Chapter 7: Integrated Waste Management 367

7.1 Integrated Waste Management 367

Index 375
Preface

This second edition arises from the 1998 first edition (published by John Wiley & Sons, Ltd 1998) which was largely based on the UK. This new book has been substantially revised and rewritten to cover waste treatment and disposal with particular emphasis on Europe. Increasingly in Europe the European Commission legislation has had a major influence on the management of solid waste and hence the need for a European focussed text. The book is aimed at undergraduate and postgraduate students undertaking courses in Environmental Science and Environmental, Civil, Chemical and Energy Engineering, with a component of waste treatment and disposal. It is also aimed at professional people in the waste management industry.

The first chapter is an historical introduction to waste treatment and disposal. The major legislative and regulatory measures emanating from the European Commission dealing with waste treatment and disposal are described.

Chapter 2 discusses the different definitions of waste. Estimates of waste arisings in Europe and the rest of the world are discussed as well as the methods used in their estimation. Various trends in waste generation and influences on them are also discussed. Several categories of waste are discussed in terms of arisings, and treatment and disposal options. The wastes described in detail are: municipal solid waste; hazardous waste; sewage sludge; clinical waste; agricultural waste; industrial and commercial waste. Other wastes described are: construction and demolition waste; mines and quarry waste; end-of-life vehicles and scrap tyres. The chapter ends with a discussion of the different types of waste containers, collection systems and waste transport.

Chapter 3 is concerned with waste reduction, re-use and recycling, with the emphasis on recycling. Municipal solid waste and industrial and commercial waste recycling are discussed in detail. Examples of recycling of particular types of waste, i.e., plastics, glass, paper, metals and tyres are discussed. Economic considerations of recycling are discussed.
Chapter 4 is concerned with waste landfill, the main waste disposal option in many countries throughout Europe. The EC Waste Landfill Directive is covered in detail. Landfill design and engineering, the various considerations for landfill design and operational practice, are described. The different main types of waste which are landfilled, i.e., hazardous, non-hazardous and inert wastes and the processes operating within and outside the landfill are discussed. The major different landfill design types are discussed in detail. The formation of landfill gas, landfill gas migration, management and monitoring of landfill gas are discussed, as is landfill leachate formation and leachate management and treatment. The final stages of landfilling of wastes, i.e., landfill capping, landfill site completion and restoration are described. The recovery of energy through landfill gas utilisation is discussed in detail. The problems of old landfill sites are highlighted.

Chapter 5 is concerned with incineration, the second major option for waste treatment and disposal in Europe. The EC Waste Incineration Directive is described in detail and the various incineration systems are discussed. Concentration is made on mass burn incineration of municipal solid waste, following the process through waste delivery, the bunker and feeding system, the furnace, and heat recovery systems. Emphasis on emissions formation and control is made with discussion of the formation and control of particulate matter, heavy metals, toxic and corrosive gases, products of incomplete combustion, such as polycyclic aromatic hydrocarbons (PAHs), dioxins and furans. The contaminated wastewater and contaminated bottom and flyash arising from waste incineration is discussed. Energy recovery via district heating and electricity generation are described. Other types of incineration including fluidised bed incinerators, starved air incinerators, rotary kiln incinerators, cement kilns, liquid and gaseous waste incinerators and the types of waste incinerated in each different type is discussed.

Chapter 6 discusses other options for waste treatment and disposal. Pyrolysis of waste, the types of product formed during pyrolysis and their utilisation as well as the different pyrolysis technologies, are discussed. Gasification of waste, gasification technologies and utilisation of the product gas, are described. Combined pyrolysis–gasification technologies are discussed. Composting of waste is described, including the composting process and the different types of composter. Anaerobic digestion of waste, the degradation process and operation and technology for anaerobic digestion are discussed. Examples of the different types of pyrolysis, gasification, combined pyrolysis–gasification, composting and anaerobic digestion systems are described throughout.

The concluding chapter discusses the integration of the various waste treatment and disposal options described in the previous chapters to introduce the concept of ‘integrated waste management’. The different approaches to integrated waste management are described.
Introduction

Summary

This chapter is an historical introduction to waste treatment and disposal. The development of waste management in the European Union through the use of various policy, strategy and legislative measures are discussed. The adoption of sustainable development by the EU through the various Environment Action Programmes is presented. The main EU Directives, Decisions and Regulations in relation to waste management are described. The Waste Strategy of the EU is presented and the policy initiatives related to its implementation are discussed. The economics of waste management across Europe are discussed. The main treatment and disposal routes for wastes in the European Union are briefly described.

1.1 History of Waste Treatment and Disposal

The need for adequate treatment and disposal of waste by man, arose as populations moved away from disperse geographical areas to congregate together in communities. The higher populations of towns and cities resulted in a concentration of generated waste, such that it became a nuisance problem. Waste became such a problem for the citizens of Athens in Greece that, around 500 BC, a law was issued banning the throwing of rubbish into the streets. It was required that the waste be transported by scavengers to an open dump one mile outside of the city. The first records that waste was being burned as a disposal route appear in the early years of the first millennium in Palestine. The Valley of
Gehenna outside Jerusalem contained a waste dump site at a place called Sheol where waste was regularly dumped and burned. The site became synonymous with hell.

Throughout the Middle Ages, waste disposal continued to be a nuisance problem for city populations. Waste was often thrown onto the streets causing smells and encouraging vermin and disease. For example, in 1297 a law was passed in England requiring householders to keep the front of their houses clear of rubbish. More than a 100 years later, in 1408, Henry IV ruled that waste should be kept inside houses until a ‘raker’ came to cart away the waste to pits outside the city (Project Integra 2002). In 1400 in Paris, the huge piles of waste outside the city walls began to interfere with the city defences.

In Europe, the industrial revolution between 1750 and 1850 led to a further move of the population from rural areas to the cities and a massive expansion of the population living in towns and cities, with a consequent further increase in the volume of waste arising. The increase in production of domestic waste was matched by increases in industrial waste from the burgeoning new large-scale manufacturing processes. The waste generated contained a range of materials such as broken glass, rusty metal, food residue and human waste. Such waste was dangerous to human health and, in addition, attracted flies, rats and other vermin which, in turn, posed potential threats through the transfer of disease. This led to an increasing awareness of the link between public health and the environment.

To deal with this potential threat to human health, legislation was introduced on a local and national basis in many countries. For example, in the UK, throughout the latter half of the nineteenth century, a series of Nuisance Removal and Disease Prevention Acts were introduced in the UK which empowered local authorities to set up teams of inspectors to deal with offensive trades and to control pollution within city limits. These Acts were reinforced by the Public Health Acts of 1875 and 1936, which covered a range of measures some of which were associated with the management and disposal of waste. The 1875 Act placed a duty on local authorities to arrange for the removal and disposal of waste. The 1936 Act introduced regulation to control the disposal of waste into water and defined the statutory nuisance associated with any trade, business, manufacture or process which might lead to degradation of health or of the neighbourhood (British Medical Association 1991; Reeds 1994; Clapp 1994). In the US, early legislation included the 1795 Law introduced by the Corporation of Georgetown, Washington DC, which prohibited waste disposal on the streets and required individuals to remove waste themselves or hire private contractors. By 1856, Washington had a city-wide waste collection system supported by taxes. In 1878, the Mayor of Memphis organised the collection of waste from homes and businesses and removal to sites outside the city. By 1915, 50% of all major US cities provided a waste collection system which had risen to 100% by 1930 (Neal and Schubel 1989; McBean et al 1995).

One of the main constituents in domestic dust bins in the late nineteenth century was cinders and ash from coal fires, which represented a useful source of energy. The waste also contained recyclable materials such as old crockery, paper, rags, glass, iron and brass and was often sorted by hand by private contractors or scavengers to remove the useful items. Much household waste would also be burnt in open fires in the living room and kitchen as a ‘free fuel’ supplement to the use of coal. The combustible content of the waste was recognised as a potential source of cheap energy for the community as a whole and the move away from private waste contractors to municipally organised waste collection,
led to an increase in incineration. Purpose-built municipal waste incinerators were introduced in the UK in the late 1870s and, by 1912, there were over 300 waste incinerators in the UK, of which 76 had some form of power generation (Van Santen 1993). One of the first municipal incinerators introduced in the US was in 1885 in Allegheny, Pennsylvania (Neal and Schubel 1989). By 1914, there were about 300 waste incinerators in the US. However, many of the waste incinerators were small-scale, hand-fed plants which were poorly designed and controlled and their operation was not cost-effective.

However, the growth of incineration was secondary to the main route to disposal, which was dumping, either legally or illegally. The ease of waste disposal to land and the move to centralised waste management through town or city authorities meant that this route increasingly became the preferred waste disposal option. Particularly as incineration plants were difficult and expensive to maintain. As these incineration plants reached the end of their operational lifetime they tended to become scrapped in favour of landfill. The waste dumps themselves however, were poorly managed, open tips, infested with vermin and often on fire. The environmental implications of merely dumping the waste in such open sites was recognised, and increasingly waste began to be buried. Burying the waste had the advantages of reducing odours and discouraging rats and other vermin and consequently the sites became less dangerous to health. Through the first half of the 20th century some improvements in landfill sites were seen, with improved site planning and site management. However, this did not apply to all areas and many municipal sites still had the minimum of engineering design and the open dump was still very common. When such sites were full, they were covered with a thin layer of soil and there was minimum regard to the effects of contaminated water leachate or landfill gas emissions from the disused site (McBean et al 1995).

The First and Second World Wars and the inter-war periods saw a rise in waste reclamation and recycling, and waste regulation and the environment became a less important issue. Following the Second World War, waste treatment and disposal was not seen as a priority environmental issue by the general public and legislature, and little was done to regulate the disposal of waste. However, a series of incidents in the late 1960s and 70s, highlighted waste as a potential major source of environmental pollution. A series of toxic chemical waste dumping incidents led to increasing awareness of the importance of waste management and the need for a more stringent legislative control of waste. Amongst the most notorious incidents were the discovery, in 1972, of drums of toxic cyanide waste dumped indiscriminately on a site used as a children’s playground near Nuneaton in the UK, the leaking of leachate and toxic vapours into a housing development at the Love Canal site, New York State in 1977, the dumping of 3000 tonnes of arsenic and cyanide waste into a lake in Germany in 1971, and the leak of polychlorinated biphenyls (PCBs) into rice oil in Japan in 1968, the ‘Yusho’ incident (Box 1.1, British Medical Association 1991).

The massive adverse publicity and public outcry led to pressure for the problem of waste disposal to be more strictly controlled by the legislature. In the UK, as a direct result of the Nuneaton cyanide dumping incident, emergency legislation was introduced in the form of The Deposit of Poisonous Waste Act, 1972. Further legislation on waste treatment and disposal followed in 1974 with the Control of Pollution Act, which controlled waste disposal on land through a new licensing and monitoring system for waste disposal facilities. The late 1980s and 1990s saw further development of waste management legislation in the UK and the increasing influence of European Community legislation. For
example; the 1990 Environmental Protection Act; the 1995 Environment Act; the 1994 Waste Management Licensing Regulations; 1994 Transfrontier Shipment of Waste Regulations; the 1996 Special Waste Regulations; the 2000 Pollution Prevention and Control Regulations and the Landfill Regulations 2002, which all contain measures in direct response to EC Directives.

Box 1.1
Waste Disposal Incidents which Influenced Waste Management and Legislation

1. Love Canal, Niagara City, New York State, USA: 1977
Love Canal, Niagara City was an unfinished canal excavated for a projected hydro-electricity project. The abandoned site was used as a dump for toxic chemical waste and more than 20,000 tonnes of waste containing over 248 different identified chemicals were deposited in the site between 1930 and 1952. Following the sale of the plot in 1953, a housing estate and school were built on the site. In 1977 foul-smelling liquids and sludge seeped into the basements of houses built on the site. The dump was found to be leaking and tests revealed that the air, soil and water around the site were contaminated with a wide range of toxic chemicals, including benzene, toluene, chloroform and trichloroethylene. Several hundred houses were evacuated and the site was declared a Federal Disaster Area. There were also later reports of ill health, low growth rates for children and birth defects amongst the residents. As the actual and projected clean-up costs of the site became known, legislation in the form of the Comprehensive Environmental Response, Compensation and Liabilities Act, 1980, was introduced by Congress. This legislation placed the responsibility and cost of clean-up of contaminated waste sites back to the producers of the waste.


2. Cyanide Dumping, Nuneaton, Coventry, Warwickshire, UK: 1972
A series of toxic waste dumping episodes occurred in the early months of 1972. The most serious of which was the dumping of 36 drums of sodium cyanide in a disused brickworks at Nuneaton, on the outskirts of Coventry. The site was in constant use as a play area by local children. The drums were heavily corroded and contained a total of one and a half tonnes of cyanide, enough, police reported, to wipe out millions of people. Over the following weeks and months further incidents of toxic waste dumping were reported extensively in the press. Drums of hazardous waste were found in numerous unauthorised sites including a woodland area and a disused caravan site. The episodes generated outrage in the population, and emergency legislation was rushed through Parliament in a matter of weeks in the form of The Deposit of Poisonous Waste Act, 1972. The new Act introduced penalties of five years imprisonment and unlimited fines for the illegal dumping of waste, in solid or liquid form, which is poisonous, noxious or polluting. The basis of the legislation was the placing of responsibility for the disposal of waste on industry. Further legislation on waste treatment and disposal followed in 1974 with the Control of Pollution Act.

In the US, in response to the increasing concerns of indiscriminate waste disposal, landmark legislation covering waste disposal was developed with the Resource, Conservation and Recovery Act (RCRA) 1976, which initiated the separation and defining of hazardous and non-hazardous waste and the separate requirements for their disposal. The RCRA was an amendment to the 1965 Solid Waste Disposal Act which was the first Federal statutory measure to improve solid waste disposal activities. However, it was the RCRA which embodied the US approach to waste treatment and disposal, establishing a framework for national programs to achieve environmentally sound management of both hazardous and non-hazardous wastes. The Act has been amended several times since 1976, by such as the Hazardous and Solid Waste Amendments of 1984, the Federal Facilities Compliance Act of 1992 and the Land Disposal Program Flexibility Act of 1996.

1.2 European Union Waste Management Policy

The European Union had its origins in the European Economic Community (EEC) which was established by the Treaty of Rome in 1958. Since then a series of Acts and Treaties, including the Single European Act (1987), the Maastricht Treaty (1993) and the Treaty of Amsterdam (1997) have resulted in the development of the organisation and governance of the European Union (Box 1.2). Included in these Acts and Treaties are the general

Box 1.2
European Governance

There are a number of bodies which are involved in the process of implementing, monitoring and further developing the legal system of the European Union. EU law is composed of three interdependent types of legislation. Primary legislation includes the major Treaties and Acts agreed by direct negotiation between the governments of the Member States, for example, the Single European Act (1987), the Maastricht Treaty (1992) and the Treaty of Amsterdam (1997). These agreements are then ratified by the national parliaments of each country. Secondary legislation is based on the Treaties and Acts and takes the form of Directives, Regulations and Decisions. The third type of legislation is Case Law based on judgements from the European Court of Justice.

There are four institutions that serve to govern the European Union:

1. The European Commission – The European Commission initiates all legislative proposals and ensures their implementation in all Member States. The Commission has a President and nineteen commissioners who are each responsible for one or more policy areas. The European Commission also has the important responsibility of administration of the EU budget. The Commission is divided into 25 Directorates-General which cover specific areas such as sustainable development, natural resources and environment and health.

2. The Council of the European Union – Laws initiated by the European Commission are put before the Council of the European Union, also known as the Council of
objectives of protecting and improving the quality of the environment. Additionally, more detailed policy statements in relation to the environment are included in Environmental Action Programmes. These Action Programmes include EU policy development in relation to waste treatment and disposal. There have been six Environmental Action Programmes since 1973. The approach and strategy in terms of waste in the successive Environmental Action Programmes has been from one of pollution control to pollution prevention and
latterly to a sustainable development approach (Gervais 2002(b)). The First Environmental Action Programme (1973–76) regarded waste as a remedial problem requiring control at Community level. The Second (1977–81) and Third (1982–86) Environmental Action Programmes emphasised the need for waste prevention, recycling, re-use and final disposal, via environmentally safe means. The need for action in regard to waste minimisation at the production process through the use of clean technologies was the policy of the Fourth Environmental Action Programme (1987–92). The Fourth Programme also emphasised the hierarchical approach to waste management of the first three Programmes. During the period of the Fourth Environmental Action Programme, a Community Strategy for Waste Management was drawn up by the EU which set out the hierarchical structure of waste management as a long-term strategy for the EU (Gervais 2002(b)). The Fifth (1993–2000) and Sixth (2001–2010) Environmental Action Programmes incorporate into the policies and strategies of the EU, the concepts of ‘sustainable development’ and the integration of environmental decision-making and policy formulation into all major policy areas of the EU. One of the main objectives of the Sixth Environment Action Programme focuses on the sustainable management of natural resources and waste. The Programme identifies the reduction of waste as a specific objective and sets a target of reducing the quantity of waste going to final disposal by 20% by 2010 and by 50% by 2050. The actions required to achieve these targets include:

- the development of a strategy for the sustainable management of natural resources by laying down priorities and reducing consumption;
- the taxation of natural resource use;
- establishing a strategy for the recycling of waste;
- the improvement of existing waste management schemes;
- investment into waste prevention and integration of waste prevention into other EU policies and strategies.

The concept of ‘sustainable development’ has developed from the 1992 United Nations Rio Conference on Environment and Development, through to the Johannesburg World Summit on Sustainable Development (2002). The concept requires that society takes decisions with proper regard to their environmental impacts. The concept tries to strike a balance between two objectives, the continued economic development and achievement of higher standards of living both for today’s society and for future generations, but also to protect and enhance the environment. The economic development of society clearly has an impact on the environment since natural resources are used and by-product pollution and waste are produced in many processes. However, sustainable development promotes development by encouraging environmentally friendly economic activity and by discouraging environmentally damaging activities. Such activities include energy efficiency measures, improved technology and techniques of management, better product design and marketing, environmentally friendly farming practices, making better use of land and buildings and improved transport efficiency and waste minimisation (Sustainable Development 1994; This Common Inheritance 1996).

The Gothenburg European Council of 2001 resulted in the European Union Heads of Government adopting a Sustainable Development Strategy. The strategy is based on the principle that the economic, social and environmental effects of all policies should be examined in a co-ordinated way and taken into account in decision-making (Sustainable
Waste Treatment and Disposal (2001). This includes the proposal that all major policy proposals should include a sustainability impact assessment.

The treatment and disposal of waste is one of the central themes of sustainable development. The approach of the European Union and its member states for the management of waste has developed via a series of Directives and Programmes into a strategy concerning the treatment of waste which has the key objectives of minimising the amount of waste that is produced and to minimise any risk of pollution of the environment.

### 1.3 Waste Strategy of the European Union

#### 1.3.1 Community Strategy for Waste Management

The waste management policy of the European Union set out in the various Environment Action Programmes is implemented through the Waste Management Strategy and subsequent legislative measures such as Directives, Regulations and Decisions of the European Union on specific waste management issues.

The initial EU strategy document on waste, the Community Strategy for Waste Management (SEC (89) 934 Final), was drawn up in 1989 as part of the Fourth Environmental Action Programme (1987–92). It was presented as a ‘communication’ to the European Commission and to the Council of the European Parliament. The Strategy set out the principles of the hierarchy of waste management through the prevention of waste by clean and improved technologies, the re-use and recycling of waste, and optimisation of the final disposal. The proximity principle, whereby waste should be dealt with as near as possible to its source and also the goal of self-sufficiency in waste treatment and disposal, were emphasised. In 1996 the European Environment Ministers adopted by Resolution a revised Waste Strategy (COM (96) 399 Final 1996). This was a review of the 1989 document and re-emphasised the need for sustainable approaches to waste management in the EU with a high level of environmental protection. Waste prevention was therefore seen as the priority and waste recovery via re-use, recycling, composting and energy from waste were hierarchical objectives. The difficulties in harmonisation of the various terms used in defining ‘wastes’ across the EU and, consequently, implementation of EU-wide legislation was recognised as a problem. Therefore the strategy called for a review of the waste definitions and catalogue of wastes. The measure of the successful implementation of waste legislation, with the aim of moving waste treatment processes up the hierarchy of waste management, depends on accurate and reliable statistical data. The common use of waste terminology and the reliable collection of accurate data via the European Environment Agency, was therefore stressed. The use of quantitative targets to reduce waste production and to increase re-use recycling and the recovery of waste, were recommended for the Member States. The Strategy also called for the need for specific emission standards in the area of waste incineration and the control of waste landfills. Specific Directives were subsequently implemented via the 1999 Landfill of Waste Directive and the 2000 Incineration of Waste Directive. The strategy also set out recommendations in the area of transfrontier shipments of waste, waste management planning at local and regional level
and encouraged the use of a broad range of instruments, including economic instruments, to achieve the policy objectives of the Strategy.

Through the measures of the Waste Framework Directive (1975) as amended in 1991 and 1996, the member states of the European Union are required to have a National Waste Strategy that sets out their policies in relation to the recovery and disposal of waste. In particular, the Strategy must identify the type, quantity and origin of waste to be recovered or disposed of, as well as the general technical requirements and any special arrangements for particular waste and suitable disposal sites or installations.

The objectives of the National Waste Strategy of Member States (Environment Act 1995; Lane and Peto 1995; Gervais 2002(b)) include:

- ensuring that waste is recovered or disposed of without endangering human health and without using processes or methods which could harm the environment;
- establishing an integrated and adequate network of waste disposal installations, taking account of the best available technology but not involving excessive costs;
- ensuring self-sufficiency in waste disposal;
- encouraging the prevention or reduction of waste production and its harmfulness by the development of clean technologies;
- encouraging the recovery of waste by means of recycling, re-use or reclamation, and the use of waste as a source of energy.

Underlying National Waste Strategies, is the ‘self-sufficiency principle’ which states that Member States shall take appropriate measures to establish an integrated and adequate network of disposal installations which enable the Union as a whole to become self-sufficient in waste disposal. A move towards individual member-state self-sufficiency, is also recommended. The development of a waste strategy should also reflect the ‘proximity principle’ under which waste should be disposed of (or otherwise managed) close to the point at which it is generated. This creates a more responsible approach to the generation of wastes, and also limits pollution from transport. It is therefore expected that each region should provide sufficient waste treatment and disposal facilities to treat or dispose of all the waste it produces.

The EU strategy on waste has developed into the concept of the ‘hierarchy of waste management’ (Sustainable Development 1994; Making Waste Work 1995; Waste Not Want Not 2002). The hierarchy was originally developed through the aims of the original 1975 Waste Framework Directive which encouraged, waste reduction, re-use and recovery with disposal as the least desirable option. The hierarchy was formally adopted in the 1989 EU Community Strategy for waste Management (Gervais 2002(b)). A more detailed version of the hierarchy has also been proposed (Figure 1.1, Waste Not Want Not 2002).

1. **Waste reduction.** Uppermost in the hierarchy is the strategy that waste production from industrial manufacturing processes should be reduced. Reduction of waste at source should be achieved by developing clean technologies and processes that require less material in the end products and produce less waste in their manufacture. This may involve the development of new technologies or adaptations of existing processes. Other methods include the development and manufacture of longer lasting products and products which are likely to result in less waste when they are used. The manufacturing process should also avoid producing wastes which are hazardous, or reduce the
1. Waste Treatment and Disposal

2. Re-use. The collection and re-use of materials, for example, the re-use of glass bottles, involves the collection, cleaning and re-use of the same glass bottle. Tyre re-treading would also come into this category, where many truck tyres may be re-treaded many times throughout their lifetime. Re-use may also include new uses for the item once they have served their original purpose. For example, the use of used tyres for boat fenders and as silage covers. Re-use can be commercially attractive in some circumstances. However, re-use may not be desirable in all cases since the environmental and economic cost of re-use in terms of energy use, cleaning, recovery, transportation etc., may outweigh its benefits.

3. Recycling and composting

   (i) Materials Recycling. The recovery of materials from waste and processing them to produce a marketable product, for example, the recycling of glass and aluminium cans is well established, with a net saving in energy costs of the recycled material compared with virgin production. The potential to recycle material from waste is high, but it may not be appropriate in all cases, for example, where the abundance of the raw material, energy consumption during collection and re-processing, or the emission of pollutants has a greater impact on the environment or is not cost-effective. Materials recycling
also implies that there is a market for the recycled materials. The collection of materials from waste, where there is no end market for them, merely results in large surpluses of unwanted materials and also wastes additional energy with no overall environmental gain.

(ii) Composting. Decomposition of the organic, biodegradable fraction of waste to produce a stable product such as soil conditioners and growing material for plants. Composting of garden and food waste has been encouraged for home owners as a direct way of recycling. It has been extended to the larger scale for green waste from parks and gardens and also to municipal solid waste and to sewage sludge. The quality of compost produced from waste, compared with non-waste sources, has been an issue for waste composting, particularly in the area of contamination.

4. Energy recovery. Recovery of energy from waste incineration or the combustion of landfill gas. Many wastes, including municipal solid waste, sewage sludge and scrap tyres, contain an organic fraction which can be burnt in an incinerator. The energy is recovered via a boiler to provide hot water for district heating of buildings or high-temperature steam for electricity generation. The incinerator installation represents a high initial capital cost and sophisticated emissions control measures are required to clean-up the flue gases. Producing energy by combined heat and power (CHP) enables the maximum recovery of energy from waste by producing both electricity and district heating. The waste is again incinerated, but CHP systems would use a different type of steam turbine which would generate a lower amount of electricity, then the steam effluent from the turbine would be at a higher temperature, enabling district heating also to be incorporated. The production of landfill gas from the biodegradation of the organic fraction of wastes such as domestic waste and sewage sludge in a landfill site, produces a gas consisting mainly of methane which can be collected in a controlled, engineered way and burnt. Again the derived energy is used for either district heating or power generation. Additionally, there are newer technologies such as pyrolysis and gasification which can recover energy in the form of gas or liquid fuels. These can then be exported to power stations or used to generate energy on site.

5. Landfill. Under the hierarchy, landfill is seen as the least desirable option. Biological processes within the landfill ensure that, over a period of time, any biodegradable waste is degraded, neutralised and stabilised to form an essentially inert material. However, methane and carbon dioxide which are ‘greenhouse gases’ are generated throughout the degradation period. The European Union, through the Waste Landfill Directive (Council Directive 1999/31/EC 1999) has set targets for the reduction of biodegradable waste going to landfill, to encourage more recycling and to reduce emissions of the greenhouse gases. Where disposal to landfill occurs, the process is controlled, ensuring that human health is not endangered or harm to the environment does not occur. Landfill sites are often used mineral workings, which are required to be infilled after use and consequently, the disposal of certain types of waste such as treated and inert wastes into landfill, can be beneficial and eventually result in recovered land. A further major consideration for landfill disposal is the leachate, the potentially toxic liquid residue from the site, which may enter the water course.

The EU waste management strategy, encompassing sustainable development, requires that waste management practices move up the hierarchy such that waste is not merely
disposed of, but should where possible be, recovered, reused or minimised. However, this may not be achievable in all cases and in some cases may not be desirable. For example, some wastes are best landfilled or incinerated since the environmental and economic cost of trying to sort and decontaminate the waste to produce a useable product outweighs the benefits. Consequently, the principle of Best Practicable Environmental Option (BPEO) has been developed (Box 1.3).

Box 1.3
Best Practicable Environmental Option (BPEO)

Best Practicable Environmental Option (BPEO) has been defined in the UK as:

‘The outcome of a systematic consultative and decision-making procedure which emphasises the protection and conservation of the environment across land, air and water. The BPEO procedure establishes, for a given set of objectives, the option that provides the most benefits or least damage to the environment as a whole, at acceptable cost, in the long term as well as in the short term’.

The principle was introduced in the UK to take account of the total pollution from a process and the technical possibilities for dealing with it. BPEO is an integrated multi-media approach which applies to polluting discharges to air, water or land and should take into account the risk of transferring pollutants from one medium to another. The option chosen requires an assessment of the costs and benefits of the appropriate measures, but does not imply that the best techniques should be applied irrespective of cost. The concept is also applied in a wider context to policy and strategy planning for waste disposal and to the management of particular waste streams. The concept implies that different alternative options have been investigated before the preferred option is chosen which gives the best environmental outcome, in terms of emissions to land, air and water, at an acceptable cost. All feasible options which are both practicable and environmentally acceptable should be identified, and the advantages and disadvantages to the environment analysed. Whilst the selection of the preferred option is subjective, the decision makers should be able to demonstrate that the preferred option does not involve unacceptable consequences for the environment. The strategy of sustainable waste management has re-emphasised the need for BPEO to be applied in a wider context such that BPEO should not be restricted to the disposal of a particular waste stream without also examining the production process to determine whether the waste can be minimised, recovered or recycled. The use of the term ‘practicable’ involves a number of parameters including that the option chosen must be in accordance with current technical knowledge and must not have disproportionate financial implications for the operator. However, the best practicable option may not necessarily be the cheapest.

Although a UK term, the link between the environmental benefits and economic effects have been discussed in terms of waste treatment in the EU Community Strategy for Waste Management (1997). There the choice of option in regard to waste recovery operations should be the best environmental option. However, the choice made should have regard both to environmental and to economic effects.

Sources: Royal Commission on Environmental Pollution 1988; Council Resolution 97/C, 76/01 1997.
1.4 Policy Instruments

The aims of the EU Strategy on sustainable waste management and the objective of moving waste management options up the waste hierarchy may be achieved by a range of policy instruments. These include, the use of regulatory measures, market-based instruments, waste management planning and statistical data policy instruments, all of which are available to the EU or Member States of the EU. For example:

1. The regulatory policy is based on the extensive EU legislative and regulatory provisions covering the management of waste. A number of key European Community Directives, Regulations and Decisions influence the management of waste across the EU including:

- Waste Framework Directive (75/442/EEC 1975);
- Transfrontier Shipments of Waste (Council Regulation 259/93/EEC);
- European Waste Catalogue (Commission Decision 2000/532/EC 2000);
- Waste Management Statistics Regulation (COM (99) 31 Final 1999);

2. The EU emphasises that waste management should reflect, as far as practicable, the costs of any environmental damage, whilst being carried out on a commercial and competitive basis. The costs of the various waste management options should fall, as far as possible, on those responsible for the creation of the waste. The fifth Environmental Action Programme included, as one of its key priorities, the broadening of the range of environmental policy instruments (Europa 2003). Environmental taxes and charges in the area of waste management can be a way of implementing the ‘polluter pays’ principle, by encouraging the use of more sustainable waste treatment and disposal options. However, there are no EU-wide economic measures, but each Member State of the EU is encouraged to develop such economic instruments to influence the choice of the waste management option. Amongst the economic instruments introduced by Member States are landfill taxes, incineration taxes, direct waste charging schemes and tradeable waste allowances.

3. The use of planning may be used as a policy measure to control and plan the location of waste management facilities. In addition, it ensures that there is adequate provision of waste management facilities, such as recycling, recovery, landfill, composting and incineration, leading to an integrated waste management structure. The ‘proximity principle’, whereby the treatment and disposal of waste should be carried out close to the point of waste production, confers more responsibility on the communities which produce the waste. In addition, regional self-sufficiency in waste management should
be a guiding principle of the planning authority. The Waste Framework Directive of 1975 was the main enabling legislation regarding waste management introduced by the EU. The Directive contained the requirement that Member States draw up a waste management plan identifying the appropriate locations and installations for waste treatment plants. For major waste management projects an environmental assessment is required, ensuring that the planned site is the most suitable location with minimum impact on the environment. Thereby, the planning authority ensures that the waste management plan or strategy of the region is implemented.

4. The statistical data policy required to meet the aims of the EU and Member State Waste Management policy, is based on the key role of statistically accurate data in waste management. To enable suitable waste strategies to be determined and industry and waste targets to be set, information on the sources, types and volumes of waste are produced, but also the proportions re-used, recovered or disposed are required. A key role in this context are the appropriate ‘competent authorities’ of each Member State of the EU, such as the UK Environment Agency, the German Federal Environment Agency (Umweltbundesamt), the Danish Environmental Protection Agency, etc. These Member State agencies are supported by the European Environment Agency. The Agency’s objective is to ‘provide the Community and the Member States with information which is objective, reliable and comparable at European level and which will enable them to take the measures required to protect the environment, evaluate the implementation of the measures and ensure that the public is properly informed on the state of the environment’ (Gervais 2002(b)). The European Environment Agency carries out the following functions (Europa 2003):

- recording, collecting, assessing and transmitting data on the state of the environment;
- providing the European Community and the member States with the objective information that they require to draw up and implement appropriate and effective environment policies;
- helping to monitor environmental measures;
- working on the comparability of data at European level;
- promoting the development and application of environmental forecasting techniques;
- ensuring that reliable information on the environment is widely circulated.

The European Environment Agency was established in 1990 as a consultative body with the aims of supporting sustainable development and helping to achieve a significant and measurable improvement in Europe’s environment. This is achieved through the provision of targetted and reliable information which is made available to policy-making agents in the European institutions and in the Member States. To this end, the Agency aims to provide a Europe-wide environmental data gathering and processing network. All the statistical data provided by the Member States is transmitted to Eurostat, the Statistical Office of the European Union. The Agency is therefore also able to evaluate the effectiveness of legislation already passed (European Environment Agency 1999). A major section of the European Environment Agency concentrates on the Theme of Waste. It has been recognised for some time that, across Europe, the data in relation to waste generation statistics, treatment and disposal routes, is inconsistent and incomplete. Consequently, in the Waste Theme, the Agency provides an EU-wide data gathering system, specifically on waste. In addition, detailed reports based on trends of waste generation, the implementation
of waste legislation and emissions data, are produced. These data feed into the various policy making and legislative bodies of the EU.

### 1.5 EU Waste Management Legislation

The strategy of the European Union regarding the management of waste throughout the Union has developed from the various Policy and Strategy documents of the EU. However, its direct applicability to the Member States of the Union is through the various Directives, Regulations and Decisions of the legislature. These include a number of key measures which apply to various waste sectors, waste streams and waste treatment and disposal processes (Box 1.4). The main EU legislation in the area of waste management is described below.

#### Box 1.4
**European Waste Legislation**

European measures do not usually operate directly in member states of the European Union but set out standards and procedures which are then implemented by the Member States via their own legislative systems. The exception are ‘Regulations’, which are directly applicable and binding in all the Member States. However, most European Community (EC) law is set down mainly in ‘Framework Directives’ a term which is commonly shortened to ‘Directives’, which set general standards and objectives. Directives may contain differing requirements which take into account the different environmental and economic conditions in each Member State. Directives are implemented into national legislation by each Member State parliament. More detailed, subsidiary ‘daughter Directives’ deal with specific subjects within the Framework Directive. ‘Decisions’ are usually very specific in nature and are individual legislative acts which are binding on the sectors involved. Enforcement of EC law is devolved to Member States, but each state is answerable to the Community as a whole for the implementation of that law.

The main legislation introduced by the EC in relation to waste are:

<table>
<thead>
<tr>
<th>Council Directive/Regulation</th>
<th>Area Covered</th>
</tr>
</thead>
</table>

*Continued on page 16*
### 1.5.1 Waste Framework Directive

The most important EU Directive concerning waste was the main controlling Waste Framework Directive introduced in 1975 (75/442/EEC 1975), which established the general rules for waste management. The Directive has been subsequently amended several times, including 1991 (Council Directives 91/156/EEC and 91/692/EEC) and 1996 (Commission Decision 96/350/EC and Council Directive 96/59/EC). The 1975 Directive set out the key objective that waste should be recovered or disposed of without endangering human health and without using processes or methods which could harm the environment. In particular, without risk to water, air, soil, plants or animals, without causing nuisance through noise or odours and without adversely affecting the countryside or places of special interest (Murley 1999). Member States of the EU were required to take the necessary measures to prohibit the abandonment, dumping or uncontrolled disposal of waste. Waste Management Plans were required to be drawn up by each of the Member States to set out how the objectives of the Directive could be met. These plans included the types and

<table>
<thead>
<tr>
<th>Council Directive</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>84/631/EEC (1984)</td>
<td>Supervision and control of transfrontier shipments of hazardous waste within the EC</td>
</tr>
<tr>
<td>85/337/EC (1985)</td>
<td>Requirement of an environmental assessment for certain prescribed developments, e.g., incinerators and landfill sites</td>
</tr>
<tr>
<td>86/278/EEC (1986)</td>
<td>Control of sewage sludge to land</td>
</tr>
<tr>
<td>91/689/EEC (1991)</td>
<td>Control of hazardous waste</td>
</tr>
<tr>
<td>91/271/EEC (1991)</td>
<td>Restriction of sewage sludge disposal to sea</td>
</tr>
<tr>
<td>259/93/EEC (1993)</td>
<td>Supervision and control of shipments of all wastes, within, into and out of the EC</td>
</tr>
<tr>
<td>94/62/EC (1994)</td>
<td>Recycling and recovery of packaging and packaging waste</td>
</tr>
<tr>
<td>94/67/EC (1994)</td>
<td>Describes operational standards and emission limits for new and existing hazardous waste incinerators</td>
</tr>
<tr>
<td>96/61/EC (1996)</td>
<td>Introduced integrated pollution prevention and control (IPPC)</td>
</tr>
<tr>
<td>999/31/EC (1999)</td>
<td>Landfill of waste, setting targets for reduction in biodegradable waste going to landfill, banning co-disposal</td>
</tr>
<tr>
<td>2000/76/EC (2000)</td>
<td>Incineration and co-incineration of all wastes</td>
</tr>
</tbody>
</table>

*Sources: Garbutt 1995; Gervais 2002(b); Europa 2003.*
quantities of waste, general technical requirements and the identification of suitable
disposal sites. These plans developed into the National Waste Strategies of each Member
State. The Framework Directive set out the principle of the hierarchy of waste management,
first to develop clean technologies which minimised the use of natural resources and
minimised the production of waste, and second to recover secondary materials from waste
by means of recycling, re-use or reclamation and the use of waste as a source of energy.

The Directive also defined what was meant by ‘waste’ but only in general terms as ‘any
substance or object listed in the Directive, which the holder discards or intends or is required
to discard’. The Directive also states that ‘the uncontrolled discarding, discharge and dis-
posal of waste is prohibited’. Member States are required to promote the prevention, recycling
and re-use of wastes and to use waste as a source of energy. Each of the Member States of
the EU was also required to establish competent authorities to control waste management
processes through a system of permits and authorisations (Murley 1999). The competent
authorities would be the Environment Agencies or their equivalent in each Member
State, such as the UK Environment Agency, the German Federal Environment Agency
(Umweltbundesamt), the Danish Environmental Protection Agency, etc. The ‘polluter
pays’ principle was also stressed, in that the producer of the waste should bear the cost of
disposal. The Directive set out the need for each Member State to produce a waste manage-
ment plan or strategy to implement the measures outlined in the Directive. In particular,
the types, quantities and origins of the wastes to be treated, the general technical require-
ments and the appropriate locations and installations for waste treatment and disposal.

The Waste Framework Directive set out a list of categories of waste, and a list of
waste disposal and waste recovery operations which were covered by the provisions of
the Directive (Tables 1.1–1.3). The limited category of wastes was later superseded

Table 1.1  Categories of waste as set out in the 1975 Waste Framework Directive

<table>
<thead>
<tr>
<th>Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Production or consumption residues not otherwise specified below.</td>
</tr>
<tr>
<td>2. Off-specification products.</td>
</tr>
<tr>
<td>3. Products whose date for appropriate use has expired.</td>
</tr>
<tr>
<td>4. Materials spilled, lost or having undergone other mishap including any materials, equipment, etc., contaminated as a result of the mishap.</td>
</tr>
<tr>
<td>5. Materials contaminated or soiled as a result of planned actions (e.g., residues from cleaning operations, packing, materials, containers, etc.).</td>
</tr>
<tr>
<td>6. Unusable parts (e.g., reject batteries, exhausted catalysts, etc.).</td>
</tr>
<tr>
<td>7. Substances which no longer perform satisfactorily (e.g., contaminated acids, contaminated solvents, exhausted tempering salts, etc.).</td>
</tr>
<tr>
<td>8. Residues of industrial processes (e.g., slags, still bottoms, etc.).</td>
</tr>
<tr>
<td>9. Residues from pollution abatement processes (e.g., scrubber sludges, baghouse dusts, spent filters, etc.).</td>
</tr>
<tr>
<td>10. Machining or finishing residues (e.g., lathe turnings, mill scales etc.).</td>
</tr>
<tr>
<td>11. Residues from raw materials extraction and processing (e.g., mining residues, oil field slopes, etc.).</td>
</tr>
<tr>
<td>12. Adulterated materials (e.g., oils contaminated with PCB’s etc.).</td>
</tr>
<tr>
<td>13. Any materials, substances or products whose use has been banned by law.</td>
</tr>
<tr>
<td>14. Products for which the holder has no further use (e.g., agricultural, household, office, commercial and shop discards, etc.).</td>
</tr>
<tr>
<td>15. Contaminated materials, substances or products resulting from remedial action with respect to land.</td>
</tr>
<tr>
<td>16. Any materials, substances or products which are not contained in the above categories.</td>
</tr>
</tbody>
</table>

by the European Waste Catalogue. Similarly, the regulations relating to individual waste disposal and recycling operations were covered in more detail by later Directives, daughter Directives, Regulations and Decisions of the EU.

1.5.2 Transfrontier Shipment of Waste Directive