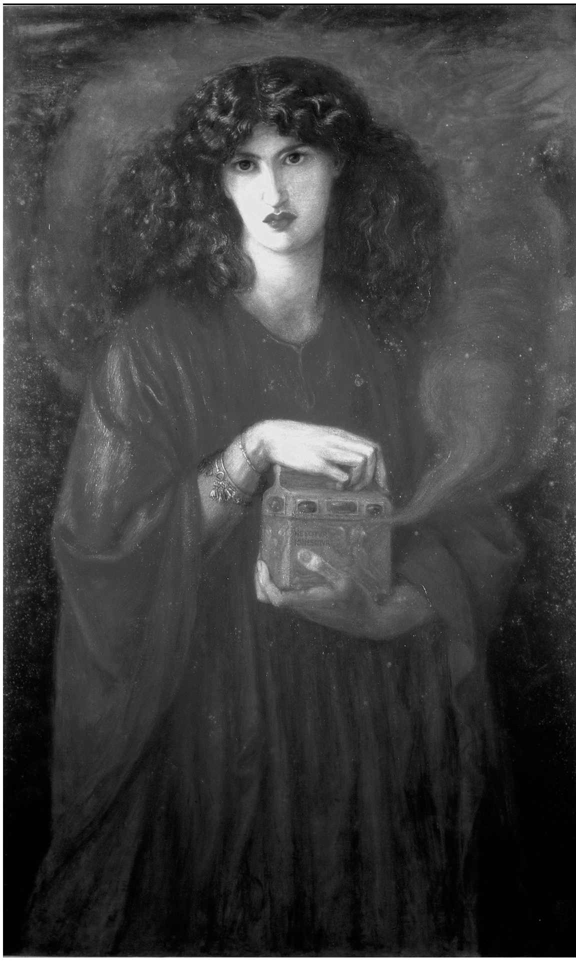

Chapter 1 – Pandora (DG Rossetti, 1871).
In Greek mythology, Pandora was the first woman, fashioned from clay by Hephaestus at Zeus' command. Pandora was made a gift of a box, containing all the ills and diseases, by Zeus to present to her future husband and thus destroy Prometheus' creation of man. Sadly, the box was opened and the ills and diseases unleashed into the world leaving only hope lingering at the bottom of the box, to console mankind – a fitting start to our examination of the environmental impacts of polymers and the ultimate hope of achieving sustainable development.

The Environment and Sustainable Development: An Integrated Strategy for Polymers

1.1 INTRODUCTION TO SUSTAINABLE DEVELOPMENT

'The existing pattern of resource use will lead to a collapse of the world system within the next century'. These were the words that hit the headlines when the world was shaken by the first oil crisis in 1973. This viewpoint, advocated in *The Limits to Growth*[1], dominated thinking throughout the 1970s and much of the 1980s and led to a wide acceptance of the depletion of resources as a central environmental, economic and political issue. It was based on the premise that natural resources, particularly oil, were about to run out. This pessimistic prediction has, however, proved to be false and the collapse of oil prices in 1986 marked the end of 'the era of resource scarcity'. New concerns over the future of the global environment then started to emerge.

One of these was the keen sense of human vulnerability to environmental changes. It soon became apparent that a unifying approach to concerns over the environment, economic development and the quality of life was necessary if human (and other) life was to be sustained for an indefinite period in the future. This approach, which developed slowly from the early 1980s and is now widely accepted, is generally referred to as Sustainable Development.

The idea of sustainable development was first used in the *World Conservation Strategy* report[2] by the International Union for the Conservation of Nature, published in 1980. It was followed in 1983 by the Brandt Commission's *Common Crisis*[3] which in effect was the forerunner of, and in many ways formed the basis to, the report *Our Common Future*[4], published in 1987 by the World Commission on Environment and Development. This publication, also known as the Brundtland report, set the benchmark for all future discussions of sustainable development and gave the most commonly used, working definition of sustainable development as that which 'meets the needs of the present without compromising the ability of future generations to meet their own needs'.

In essence, the Brundtland report called for policies which foster economic growth but also satisfy the needs of people and improve quality of life without depleting the environment. This vision of sustainable development required a different attitude to economic development, in which the quantity of growth is replaced by the quality of growth.

The Brundtland report prompted numerous actions at both national and international levels, which called on governments, local authorities, businesses and consumers to define and adopt strategies for sustainable development. One of the most notable of these activities, instigated as a direct consequence of the emergence of the concept of sustainable development, was the Earth Summit held in Rio de Janeiro in June 1992. The Summit was attended by 120 world leaders and representatives from over 150 countries and adopted a comprehensive action plan known as Agenda 21[5], for the pursuit of sustainable development.

In response to the Agenda, many governments and organisations started developing their own plans of action and setting out strategies for sustainable development. Countries such as Sweden, Canada, Germany and the UK have already started working towards their own sustainability targets and, more recently, the EU sustainable development strategy[6] has also been adopted.

1.2 SUSTAINABLE DEVELOPMENT ISSUES

Sustainable development may be regarded as the progressive and balanced achievement of sustained economic development, improved social equity and environmental quality[7]. This concept has both spatial and temporal dimensions as it must satisfy these three goals equally across the globe for both present and future generations. Although holistic in concept, sustainable development comprises three individual components (society, environment and economy) and the goals of sustainable development can only be achieved if all three components can be satisfied simultaneously (see Figure 1.1). For this to happen, a number of global and local problems need to be addressed.

One major issue is global inequity and widespread poverty: 20 % (1.2 billion) of the world's population receives nearly 83 % of total world income. There are significant links between poverty and the environmental quality and much of the environmental degradation we see in the developing world arises as a result of people seeking basic essentials of life: food, water, *etc*. On the other hand, environmental problems are a significant cause of poverty and generally hit the poor hardest, *e.g.* a quarter of all diseases are found in developing countries. One of the main causes of environmental degradation, however, is unsustainable development by the rich. The 'big seven', *i.e.* USA, Japan, Germany, Canada, France, Italy and the UK, make up less than 12 % of the world's population, but consume between 55 and 65 % of world resources. If the rest of the world continued to consume the energy resources as the UK does today, we would need eight and a half planets to sustain current global consumption in 2050 (see Figure 1.2). The patterns of consumption and distribution of resources cannot be sustained if, as currently predicted, the world population grows to 10 billion by the end of the 21st century.

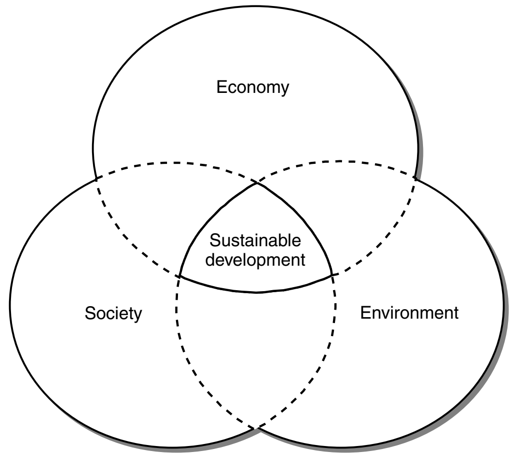

Figure 1.1 The three components of sustainable development

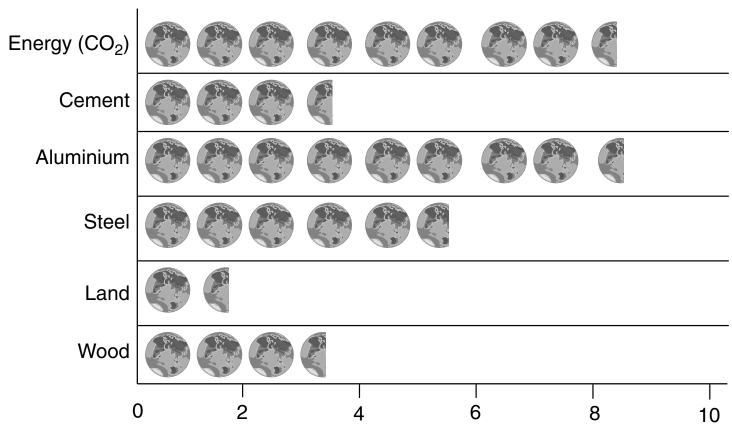

Figure 1.2 Number of planets needed to sustain current global consumption in 2050 if all countries consumed as the UK does today[8]. (Key facts for resource consumption: 12 % of the world's population consume:

- 43 % of the world's fossil fuel production;
- 64 % of the world's paper;
- 55–60 % of all the aluminium, copper, lead, nickel and tin). Reproduced with permission from McLaren *et al.* (1998). Tomorrow's World: Britain's share in a Sustainable Future. Copyright. Friends of the Earth/Earthscan.

Key Facts

- 20 % of the world population receives 83 % of the total income.
- 12 % of the world population consumes 55–65 % of world resources.
- Europe generates some 2.6 billion tonnes of waste a year.

Coupled with other global environmental problems such as climate change and loss of biodiversity, there are clear indications that we are now exceeding the 'carrying capacity' of the environment. This is exacerbated by local or regional issues, such as air pollution and generation of solid waste. For example, some 2.6 billion tonnes of industrial, agricultural and domestic waste is generated each year in Europe alone. The decreasing capacity of landfills and their recognised impact on the environment give waste management a high priority at the local and regional levels.

To enable the move towards sustainability on the practical level, it is first necessary to understand these causes of unsustainability, then to identify more sustainable options and finally to determine how they may be implemented. In doing so, it is paramount that problems and solutions are analysed by adopting more holistic, life cycle thinking. This requires a paradigm shift from the current, fractured view of the environment, with the emphasis on one stage of the life cycle (*e.g.* the production process), to a whole life cycle approach, which examines the consequences of human activities on the environment from 'cradle' (extraction of resources) to 'grave' (disposal of waste)[9,10].

In this book, we adopt such an approach in an attempt to examine the options and contribute towards the practice of sustainable development by addressing two important areas: resource use and waste management. We concentrate on polymeric materials and products, ubiquitous in our everyday life, to try and understand what drives and limits their production, use, re-use and recycling. We will consider a wide range of polymers, but will mainly concentrate on plastic* materials, *i.e.* thermoplastics and thermosets, because they constitute the majority of the market. The conceptual approach adopted in the book is illustrated in Figure 1.3, which shows a 'life guide' for polymers with a number of different lives (or cascades of uses) and the associated life cycle stages. The guide through the chapters is also shown in the figure. We particularly concentrate on post-consumer waste management and examine the influencing technical, legislative, environmental, economic and social factors with the aim of identifying more sustainable options for polymer re-use and recycling.

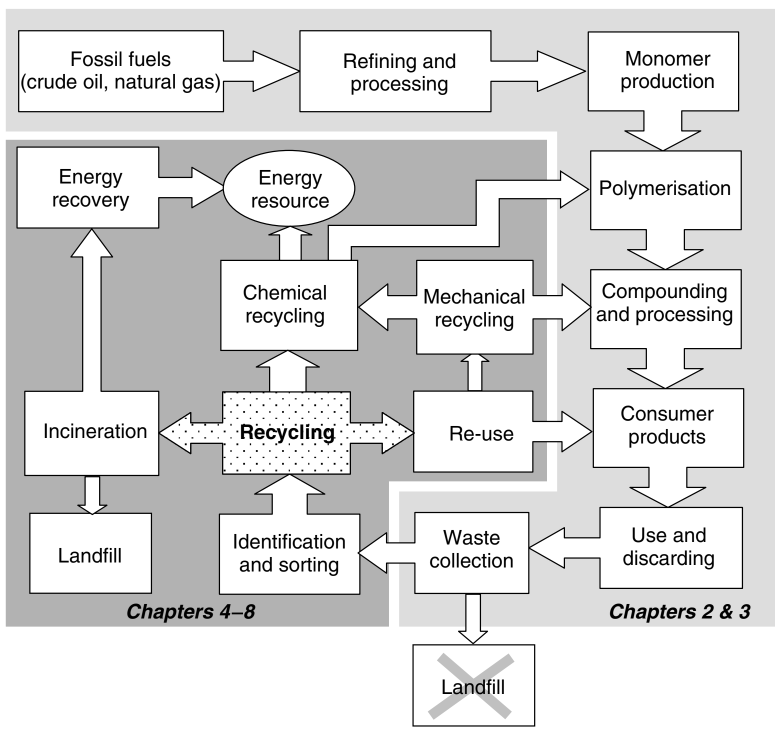

Figure 1.3 A 'life guide': following polymeric materials and products through cascades of uses from 'cradle to grave' (note that both energy and materials are consumed in every life cycle stage)

Before looking into these issues in detail in the chapters that follow, we continue here to examine why polymers may be an issue for sustainable development.

*We use the term 'polymer' as a chemical term to describe a macromolecule and the term 'plastics' as a generalisation which covers all polymeric materials but, strictly speaking, 'plastic' defines the stress/strain behaviour of the material and should really only be applied to thermoplastics and thermosets (see Chapter 2).

1.3 POLYMERS: AN ISSUE FOR SUSTAINABILITY

The emergence of the concept of sustainable development has once again made fossil fuels an issue, because it is clear that reserves will run out on time scales relevant to sustainable development, although perhaps not as soon as was predicted in the 1970s. However, scarcity of resources is not the only issue to be considered, since burning fossil fuels affects climate change and it is now widely accepted that the millions of tonnes of CO_2 produced each year by burning fossil fuels are one of the main causes of global warming. We must therefore rethink our use of such fuels and general consumption patterns into a more sustainable model.

Most synthetic polymers are derived from fossil fuels, *i.e.* from naphtha or natural gas (see Figure 1.3), which puts them immediately into the environmental 'spotlight'. Consumption of fossil fuels and the associated environmental damage have made polymeric materials and products a focus of much attention by various environmental and government groups (see Figure 1.2). They have argued that polymers use material and energy resources, which are then lost when the polymers are disposed of, usually in landfill. The production process itself also results in a loss of 'feedstock' energy. For example, the production of 1 tonne of high density polyethylene (HPDE) loses 17.9 GJ of the 71.4 GJ of calorific value in the naphtha feedstock. Put another way, some 40 % of the energy of the original crude oil is lost during processing[11].

However, the consumption of material and energy resources is not the only issue surrounding polymeric materials and products. Because of their widespread use and our 'linear' consumption patterns (in which materials and products are used only once and then discarded), polymers also contribute to an ever-increasing amount of solid waste. Since the 1930s, the total world production and consumption of polymers have risen rapidly to reach figures in excess of 100 million tonnes in 1995, about a quarter of which was produced in Europe. The types of material involved include plastic products (made from both thermoplastics and thermosets), fibres (*e.g.* textiles), elastomers, coatings and adhesives. In Western Europe around 45, mainly multinational companies, produce the basic polymer, which is sold to around 30 000 small- and medium-sized companies. These, in turn, convert the polymer into products for use in many sectors, for example, packaging, automotive parts and electronic equipment. Since 40 % of plastics are used for packaging, it is not surprising that this product category has attracted most attention from policy makers and environmentalists. For example, the total plastics consumption in Western Europe in 1999 was 33.5 million tonnes or 84 kg of plastics *per* person[12], 19 million tonnes of which were available for collection as waste, with the rest remaining in use. Because packaging has a much shorter life than, for instance, plastics used in the construction or automotive industry, it reaches the waste stream much more quickly, which explains the fact that 70 % (or 13 million of tonnes) of the total plastics waste that appeared in the same year was packaging.

On average, polymers account for 7 – 8 % by weight and 20 % by volume of municipal solid waste in Europe and elsewhere. Of that, still relatively little is recycled. For example, in Western Europe only 6 million tonnes or 30 % of the total post-consumer waste were recycled in 1999[12], with the rest going to landfill. Similar trends are found in other parts of the world. Not only does this practice waste valuable resources, but it also has negative impacts on the environment. Very few polymers are biodegradable so that, once in a landfill, they will remain there occupying space for a long time; according to some estimates, up to 200 years for some polymers. However, some of the additives used to improve polymer properties can leach from a landfill to contaminate the water table; or in poorly managed landfills burning of plastic waste can generate toxic substances and cause air pollution.

Furthermore, as we all know, not all polymer waste reaches the landfill; much of the waste also remains abandoned and scattered in the streets of our cities and towns, as well as in the countryside, affecting the aesthetic aspects of life.

Key Facts

- 40 % of the energy of crude oil is lost during the manufacture of high density polyethylene.
- World consumption of polymers reached 100 million tonnes in 1995.
- 40 % of plastics are used for packaging, 84 kg *per* person *per annum* in Europe in 1999.
- Polymers account for 7 – 8 % by weight of post-consumer plastic waste.
- 70 % of post-consumer waste in Europe went to landfill in 1999.

It is thus apparent that continuing with the same 'make–use–discard' practice is unsustainable because it leads to generation of waste, loss of resources (material and economic), environmental damage and also raises social concerns. Hence, we need to identify more sustainable practices for polymeric materials and products. The following section gives an overview of the options available, which are then considered in more detail later in the book.

1.4 INTEGRATED RESOURCE AND WASTE MANAGEMENT

Key Facts

- 4 % of the world's oil reserves are used in the manufacture of polymers.
- Waste management involves reduction, re-use, recycling, incineration and finally landfill as some waste is unavoidable.

The fact that only 4 % of the world's oil reserves are used in the manufacture of polymers is sometimes used as an argument that they do not contribute much to the degradation of the environment, but 4 % still represents a valuable resource. Furthermore there are other issues to consider, such as the generation of (long-lived) solid waste and pollution associated with polymeric materials and products. Hence addressing the problem of polymers in the environment remains an important goal.

The use of resources and management of waste in a more sustainable fashion cannot be achieved in any single way. However efficiently we use resources, the laws of thermodynamics teach us that some waste will always be generated. This, coupled with increasing consumption and the fact that it is difficult to persuade people to change their life styles, requires an integrated resource and waste management strategy. The waste management hierarchy shown in Figure 1.4 involves following the options of reduction, re-use, recycling, incineration and landfill.

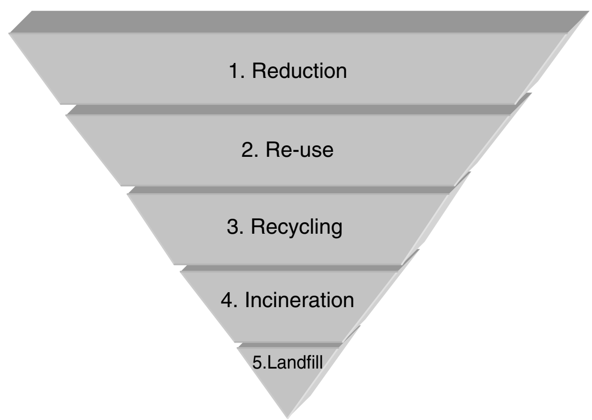

Figure 1.4 Resource and waste management hierarchy in a decreasing order of desirability

The most desirable option in this hierarchy is reduction of resource use, which also leads to a reduction in the generation of waste. The next two options are aimed at turning waste back into resources through re-use and recycling of materials, leading to conservation of natural resources and reduction of other environmental damage. Thus, adopting a 'more with less' approach maximises benefits from products and services, uses the minimum amount of resources and rejects the least amount of waste or emissions to the environment. In essence, the production of waste is seen as a demonstration of the inefficient management of resources. This is very much in harmony with the laws of nature, where there is no such thing as waste. All biological systems are interconnected and what is waste for one system is a valuable resource for another. This concept is also known as the industrial ecology of materials and further reading on the topic is provided by Graedel and Alenby[13].

The last two options in the hierarchy are incineration (without energy recovery) and landfill. Because they both waste valuable resources, with incineration also contributing to air pollution, they are not considered to be sustainable options. However, it should be borne in mind that, even with the first three options fully implemented, some waste is still unavoidable and has to be disposed of by either incineration or landfill.

The following sections provide a brief overview of each of the options relevant to polymeric materials and products.

1.4.1 Reduction

The aim for the future must be to design products so as to minimise the use of materials and energy in the manufacturing and use stages and minimise waste and emissions to the environment, a concept known as dematerialisation. There are various ways to dematerialise our economy and the reader is referred to the book by Jackson[14] for a detailed exposition on the subject.

Various approaches have been developed to facilitate reduction of resource use and they are known collectively as Design For the Environment (DFE). They apply life cycle thinking and use Life Cycle Assessment (LCA) as a tool to enable the design of products, which not only minimise the use of resources but are also easy to disassemble, re-use and recycle. LCA follows a product or an activity from 'cradle to grave', *i.e.* from the extraction of raw materials, the production and use, the re-use and recycling options to the final disposal. It quantifies environmental impacts associated with each of these stages to provide a full picture of the impact of an activity on the environment. Taking such a holistic approach to design ensures that environmental impacts are not merely shifted upstream or downstream in the supply chain, thus giving a true picture of the total consequences of an activity on the environment. This approach also enables innovation and technological improvements by identifying the 'hot spots' or major concerns that need addressing. The general principles of DFE and LCA and their application to polymers are discussed in detail later in this book.

DFE principles have already been applied to polymers, particularly to plastic products, which has led to an average decrease in the weight of plastics packaging of approximately 28% in the last 10 years[15]. Dematerialisation has saved more than 1.8 million tonnes of plastics (over the 10 years), which is greater than the total volume of mechanically recycled post-user plastics for all applications in 1998 (1.6 million tonnes). The additional benefits of reducing the weight of products are reduced environmental impacts and costs associated with their transportation.

Finally, it is also important to mention that the use of plastics compared to other alternatives can save materials and energy. For instance, in Western Europe the automotive sector uses 1.7 million tonnes of plastics a year, made from the equivalent of 3.25 million tonnes of oil. However, it is estimated that 12 million tonnes of oil are saved each year through fuel efficiencies, because vehicle components manufactured from plastics are lighter than metal equivalents, leading to a saving in CO_2 emissions of 30 million tonnes a year[15]. In the same reference, it is claimed that the use of nonplastic packaging would increase overall packaging consumption by 291% by weight, with an increase in manufacturing energy of 108% and volume of waste of 158%. Another estimate also shows energy savings in the use of plastic packaging compared to the alternatives: the projected savings made each year are enough to power a city of 1 million homes for roughly 3.5 years[16]. However, these results have to be interpreted with care as they refer to the use stage only and do not include other life cycle stages, such as extraction and processing of raw materials, manufacture of packaging and post-consumer waste management.

Reduction of resource use through better design is not sufficient on its own, unless it is accompanied by more sustainable consumption. Although we have seen substantial dematerialisation in many parts of the economy in the past years, the benefits have hardly been obvious and the main reason for that is a constant increase in consumption. One typical example is the use of mobile telephones. Although their weight and the amount of materials used for the manufacture have gone down in the past few years[17], by at least a factor of 10, the market has expanded so much that the resources used for their manufacture have in fact increased. In 1997 alone, 100 million mobile telephones were

Key Facts

- Design For the Environment reduces the use of resources and facilitates re-use and recycling.
- Life Cycle Assessment quantifies the environmental impact of a product 'from cradle to grave'.
- Dematerialisation has saved 1.8 million tonnes of plastics over the last 10 years.
- 12 million tonnes of oil are saved each year in transportation, because plastic components in vehicles are lighter than the metal equivalents.

Key Facts
- Moving from profligate consumption to prudent use of resources requires a change in lifestyle.
- Re-use is impeded by dispersion of products in the marketplace, ease of disassembly and reluctance of consumers to accept products that are not brand new.
- Re-use is ultimately limited by degradation of the material's properties.

sold world-wide; sales in Western Europe, for example, grew by a factor of 18 in the period 1991–1997[17]. Given their fairly short lifetime and obsolescence due to technological developments, they generate annually a large amount of waste (1080 tonnes in Western Europe in 1997[17]). Add to that the fact that, on a life cycle basis, the industrial operations for their manufacture generate solid waste roughly 200 times the weight of the telephone itself[18], and you can see the scope of the problem.

Moving away from profligate consumption towards more prudent use of resources will inevitably require some changes to our life styles. At present, few people are prepared to accept or do that. This therefore remains an option that has to be viewed as a long-term target. In the meantime, we have to pursue the other, short- to medium-term objectives as defined by the integrated strategy for resource and waste management. Hence, the next option to examine is resource re-use.

1.4.2 Re-use

One of the reasons for the widespread use of polymers is their versatility and, in particular, their strength and durability. The same properties can be exploited for their re-use in further applications and some manufacturers are already reclaiming plastic parts from their used products to re-use them in new products. One of the typical examples is Xerox who re-use plastic (and other) parts from old photocopiers in the manufacture of new machines.

Although this remanufacturing process is gaining wider acceptance, particularly among the manufacturers of cars and electrical and electronic equipment, there are at least three obstacles to its becoming a normal practice. Firstly, the manufacturer must be able to recover their products from customers. Since most products are sold on an individual basis, they become highly dispersed in the marketplace and it is impossible for the original manufacturers to keep track and reclaim them back from customers. In many cases, the customer does not necessarily want to own an artefact, but wants the service it delivers, so one way to overcome the recovery problem is to switch from sale of articles to leasing. In this way, the manufacturer sells a service and retains ownership of the product. It then becomes a simple exercise to recover it at the end of its life[19]. This is the approach taken by Xerox, who lease photocopiers and, in effect, sell the photocopying service rather than the machines.

Secondly, the re-use of parts from products recovered at the end of their useful life also depends on the design of a product, *i.e.* how easy it is to disassemble into its constituent parts. Complex products are particularly difficult to dismantle and the parts can be damaged during the process, making them unusable. Many electronic products are designed this way, including mobile telephones and TV equipment. Here, a DFE approach to manufacture would facilitate dismantling/disassembly and re-use.

The third obstacle to re-use is customer perception: many people are still reluctant to accept products which are not brand new, because they believe that the performance of remanufactured products is inferior to that of new products. Reducing the price of remanufactured photocopiers is one of the ways in which Xerox try to encourage their customers to lease these rather than brand new machines. On the other hand, consumers are prepared to re-use individual polymer products in their households. For example, many people are routinely re-using plastic shopping bags, containers and water bottles so that these products effectively stay longer in the use phase than originally intended by the manufacturers.

However, the number of re-use cycles is limited and eventually the properties of polymers start to deteriorate to the point when they can no longer be used without further processing. This brings us to the third option in the resource and waste management hierarchy, *i.e.* recycling.

1.4.3 Recycling

At the end of their first life cycle, or perhaps after being re-used several times, polymers can be recycled to yield new polymeric materials or products. The following options exist to take further advantage of the valuable material and/or energy resources still stored in them:

- mechanical recycling,
- chemical recycling,
- energy recovery.

The mechanical and chemical recycling options are collectively termed 'material recycling' because they recycle plastics back into usable materials or fuels respectively, as distinct from the third option that recovers energy.

As mentioned earlier, in this book we are particularly concerned with the recycling options for polymers so they will be discussed at length later. Here, however, we give just a brief overview of each option, before continuing on to talk about waste management policies that influence recycling.

Key Facts

- Mechanical recycling requires a clean and homogenous waste stream.
- Chemical recycling may be suitable for mixed plastics waste.
- Incineration/ combustion of waste plastics recovers their high calorific content if used to generate heat or power.

Mechanical Recycling

Mechanical recycling uses physical and mechanical means, such as grinding, heating and extruding to process waste plastics into new products. It requires clean and homogeneous waste, which means that plastics have to be sorted by type and separated before they can be incorporated in virgin polymers of the same type, or used on their own. The availability of homogeneous waste streams of known characteristics is thus a key criterion for successful recycling.

Chemical Recycling

This is another form of material recycling, which is particularly well suited to mixed plastics waste. It uses chemical processes to break the polymers down into their chemical constituents and convert them into useful products, such as basic chemicals and/or monomers for new plastics or fuels. As in mechanical recycling, some pretreatment of plastic waste is required to meet the specification of the recycling process.

Energy Recovery

If material recycling is not viable or after certain products have been removed from the waste stream for mechanical recycling, the high calorific value of plastic waste can be recovered as energy[20]. Energy recovery can be achieved by direct incineration, *e.g.* in municipal waste incinerators to generate heat and electricity; or waste polymers can be used directly in production processes to replace other fuels (*e.g.* in cement kilns) or for power generation.

At present, the majority of post-consumer waste is recycled as energy, followed by mechanical recycling and, at much lower rates, by chemical recycling. The rates of recycling are different in different countries but overall they are still very low. In Western Europe only 30 % of polymer waste is recycled and the rest goes to landfill. However, there is an indication that the recycling rates may be increasing. For example, according to some estimates, mechanical recycling in Western Europe has the potential to double in the period 1995–2006 from 1.2 million tonnes to 2.7 million tonnes[20].

Choosing the best recycling option is not an easy task because each case is different and many different factors have to be taken into account. These include the suitability of material for each waste management option, location, transport, infrastructure, technological developments, economic viability and end markets. It is also important to ensure that the resources used in the overall recycling operations do not exceed the environmental benefits of recycling. These and other aspects of recycling are discussed in detail later in the book.

1.4.4 Incineration (Without Energy Recovery)

Unlike energy recovery, which reclaims the energy embedded in waste plastics and is hence considered to be a recycling option, incineration without energy recovery only reduces the volume of solid waste and is thus regarded as a waste disposal option. Because it wastes valuable resources, disposal by incineration is considered to be unsustainable. It also raises a number of health and environmental concerns, due to the potential for toxic emissions from combustion (*e.g.* dioxins and heavy metals). However, the latter concerns also exist for incineration with energy recovery and both options are becoming increasingly unpopular with the public.

Key Facts
- Incineration without energy recovery and disposal in landfill wastes natural resources and valuable land space.
- Carbon taxes and tradable pollution permits are designed to discourage the production of waste.

1.4.5 Landfill

Like incineration, 'landfilling' is also becoming socially unacceptable because of its impacts on the environment and the loss of valuable resources. In addition to these concerns, there is also a problem of finding space for new landfill sites as the existing facilities reach their capacity limits. Hence, waste management policies currently being developed around the world make little allowance for disposal of waste by landfill.

The following sections examine some of these policies and how they affect management of resources.

1.5 RESOURCE AND WASTE MANAGEMENT POLICIES FOR POLYMERS

The key to achieving sustainable resource and waste management involves changing the behaviour of governments, industry and individuals and one way to facilitate change is to design appropriate policies, which maximise resource efficiency and reduce waste generation.

Environmental policies are defined either by legislation or through voluntary agreements between interested parties. Until relatively recently, the emphasis has been on the former and the 'command and control' approach has been predominant. For example, pre 1987 there were 200 command-and-control directives in the European Union (EU). More recently, the emphasis has shifted to the application of economic and market-based instruments such as carbon tax and tradable pollution permits that actively discourage the generation of waste.

Industrial organisations are also instigating various parallel voluntary initiatives ranging from 'waste minimisation', 'zero emission' and 'industrial ecology' projects through 'responsible care' to 'product stewardship' and 'take-back' schemes[9]. They are aimed at improving the environmental performance of industrial activities through the whole life cycle of a product or process. In order to encourage these trends, more progressive governments provide an incentive in the form of financial or other support. This approach, complemented by market-based instruments (*e.g.* carbon tax), provides greater flexibility in the way the targets are achieved and encourages change in industry and society in a more general way than can be achieved by stringent legislation.

However, voluntary agreements are still quite rare and have had only modest success so far[21], thus legislation remains one of the major drivers for more sustainable resource and waste management. We explore both voluntary and legislative aspects of policies and their implementation in different countries in more detail later in the book. Here we continue to give a brief overview of legislation and its implications for polymeric materials and products. As a comprehensive review of legislation around the world is outside the scope of this book, we concentrate below on the EU as an example of how policies have developed and what the future trends in resource management might be in this part of the world.

1.5.1 EU Legislation

European environmental policy is developed through Action Programmes, which set out action plans related to the environment, usually over a period of 5 years. The Fifth Environmental Action Programme[22] covered the period of 1995–2000 and has now been superseded by the Sixth Action Programme. Both Action Programmes embrace the concept of sustainable development and in particular Agenda 21 (mentioned earlier in the chapter). The Fifth Action Programme adopted the resource and waste management hierarchy shown in Figure 1.4.

Legislation on resource and waste management is one of the key areas of environmental policy development in Europe. It is dominated by the harmonisation of related laws and the development of radical proposals, which encourage more efficient use of resources and re-use of wastes. One of the most important changes in EU policy regarding waste management is the principle of 'producer responsibility'. This policy imposes on producers the obligation to recycle, recover or re-use their products. The development of this policy has been through the imposition of a duty to recover packaging waste and is a flagship for other impeding legislation in this area, including the directives on Waste Electronic and Electrical Equipment (WEEE) and End-of-Life Vehicles, as we shall see below.

The most recent proposal on Integrated Product Policy (IPP) aims to harmonise the existing pieces of legislation and contribute towards more sustainable resource and waste management. IPP would extend the responsibility of manufacturers to cover the environmental impacts of their products throughout their life cycle. It is a natural development from the existing policies on producer responsibility, which are currently concerned with the disposal of waste products at the ends of their lives. The European Commission is currently debating this proposed policy but many questions such as market distortion require resolution before they make firm proposals.

The following sections give an overview of the three EU Directives most directly related to polymer products and materials. The reader interested in further detail on waste legislation in Europe and the UK can consult Appendix 1.

Key Facts

- Legislation, based on 'Action Programmes' is one of the key areas of environmental policy development in Europe; the concept of 'producer responsibility' makes the producer responsible for waste management.
- Directives on packaging, packaging wastes and end-of-life vehicles aim to reduce the disposal of waste and to promote re-use and recycling.

Directive on Packaging and Packaging Waste

This Directive[23] set out to harmonise measures designed to reduce the production of packaging waste, by recovering it in some way, thus reducing the amount remaining for final disposal. Packaging is defined to include products made from any material such as plastic, paper/cardboard, metal, wood and glass, used to contain or protect goods or to assist in their handling, delivery or presentation. The Directive set targets for the recovery of packaging by the year 2001, which included the requirement to recover a minimum of 50% and a maximum of 65% of packaging material by weight. Furthermore, it also specified a material recycling rate of 25–45% (with a minimum allowable figure of 15% for any single material type) and required the setting up of identification, return, collection and recovery systems.

Directive on End-of-Life Vehicles

The European Parliament and Council Directive of 18 September 2000[24] on end-of-life motor vehicles lays down measures intended to prevent waste from vehicles and provides for the re-use, recycling and other forms of recovery of end-of-life vehicles and their components. Consistent with other European policy, its aim is to reduce the disposal of waste and to improve the environmental performance of all of the economic operators involved in the life cycle of vehicles and especially the operators directly involved in the treatment of end-of-life vehicles. The Directive proposes several recovery, re-use and recycling targets, including recovery and re-use of 85% by weight of vehicles by 2005, rising to 95% by 2015. The effect of this Directive will be to force manufacturers to take back scrap cars or to meet a substantial part of the cost of recycling. Since plastics are a significant proportion of a car make-up, it also directly affects polymeric materials.

Waste Electrical and Electronic Equipment

Another directive on producer responsibility is the Directive on Waste Electrical and Electronic Equipment (WEEE) adopted by the European Parliament in May 2001[25]. It lays down measures intended to reduce the disposal of waste electrical and electronic equipment through re-use, recycling and other forms of recovery. This will obviously include plastic materials, which make up a large proportion of such equipment. These measures are to be effective within 5 years, with a minimum rate of collection of 4 kg on average *per* inhabitant *per* year by the end of 2005. Its objectives are similar to those contained in the end-of-life directive in that it aims to improve the environmental performance of all economic operators involved in the life cycle of this equipment. It requires producers to provide for the collection of waste electrical and electronic equipment from holders other than private households. When supplying a new product to private households distributors are expected to offer to take back, free of charge, similar waste electrical and electronic equipment in exchange. Suppliers and governments will have to establish systems for the treatment of waste and inspection procedures for the treatment facilities. The proposal also requires the recovery of equipment from private households and other users, and the provision of specific information for both users and for treatment facilities.

Key Facts

- Car manufacturers will be required to take back or pay for disposal of scrap cars by 2015.
- 4 kg of waste plastics in electrical and electronic equipment should be collected *per* person *per* annum in Europe.
- The landfill directive seeks to reduce the amount of biodegradable material sent to landfill and hence reduce methane emissions.

The Landfill Directive

The Landfill Directive[26] took 9 years to reach the implementation stage, because of the degree of disagreement and disparity in disposal methods for waste adopted across the European Community. The main thrust of the Directive is the reduction in the amount of biodegradable municipal waste sent to landfill, with the objective of a commensurate reduction in the production of methane gas. The targets for the UK, for example, are reduction by 25 % of the 1995 level by 2010; 50 % by 2013 and 65 % by 2020. The UK has a longer period in which to make the reductions than some other European countries, because of the amount of municipal waste currently being sent to landfill. In the context of polymers, this directive is mainly relevant to the biodegradable plastics, which are currently being developed (see Chapter 8). Added to the fact that biodegradation wastes a valuable resource, this may act as a hindrance to further developments of these types of materials.

In summary, the EU is actively developing resource and waste management policies that have the potential to lead to a more sustainable use of resources. Similar policies are also being developed in other parts of the world, including the USA, Canada and Japan and they will act as a major driver for the recovery and re-use of waste materials. However, their success is also hampered by a number of technical, economic, environmental and social barriers, that limit recovery and recycling of polymeric materials in particular, and which we will discuss further in later chapters. These constraints can only be overcome by a concerted effort from all sections of society, including government, industry and individuals. In the rest of this book we will discuss the role of each group and examine, using practical cases and examples, how polymeric materials and products can be made more sustainable, but first we will explain the structure of the book.

1.6 THE BOOK STRUCTURE AND 'LIFE GUIDE'

We have already highlighted the fact that life cycle thinking is fundamental to sustainable development. We have therefore adopted this approach in analysing the options for re-use and recycling of polymers and it is embedded in the structure of the book. So each chapter follows polymers through different stages in one or more of their life cycles.

The aim of this chapter has been to provide a 'life guide' by highlighting the issues pertinent to the whole life cycle of polymers in the context of sustainable development. In Chapter 2 we continue on to explore the 'facts of life' and discuss polymer properties and how they may influence their different lives later on. In Chapter 3, we discover how a polymer's 'first life' begins and what happens to polymers when they reach the end of their useful life. 'Second life and beyond' is the subject of Chapter 4, which examines the different recycling options and technologies available for polymers. Chapter 5 discusses 'life forces', or the drivers for recycling and the barriers and how they may be overcome. In Chapter 6, we look at the 'sharp end' of a polymer's life and discuss design for the environment (DFE) as one of the options for reducing the use of resources. In the same chapter we discuss 'life after life' or cascades of uses of polymers, enabled through design for the environment. Then in Chapter 7 we compare the environmental implications of different recycling options and try to identify a 'better life' by comparing the different alternatives. In the eighth and final chapter we look beyond today and wonder what 'life hereafter' might bring for polymers and the implications changing technologies and social patterns could have for the environment and sustainable development.

We hope that you stay with us to discover some (but not all) of the answers to the 'meaning of life' in the context of the impact of polymers on the environment.

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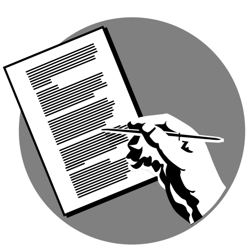

1.8 REVISION EXERCISES

1. Define sustainable development in your own words and list five global economic, social and environmental issues that need to be addressed urgently. Explain how you think they could be solved.

2. One of the objectives of sustainable development is the satisfaction of human needs. Make a list of the needs that you personally would like to satisfy. Now compare this with Maslow's heirarchy of needs (see Further Reading). Compare your priorities with your friends and discuss the differences. On a global level, how do you think these priorities differ between different countries and cultures? What does that tell you about how easy or difficult it is going to be to satisfy everyone's needs? And how about future generations?

3. Explain what you understand by 'life cycle thinking'. Why is that important for sustainable development?

4. What is Life Cycle Assessment? How is that different from 'life cycle thinking'?

5. Visit the APME web site and answer the following question: How can plastic materials contribute to sustainable development? Give examples of how plastics contribute to the environmental, economic and social components of sustainable development.

6. If plastic materials contribute to sustainable development, why are they an issue?

7. Summarise the options in the resource and waste management hierarchy and give examples relevant to polymeric products and materials for each option.

8. How can government, industry and individuals help towards more sustainable use of resources? Support your answers by giving examples relevant to polymeric materials.

9. Which EU Directives are directly related to polymeric materials? How do you think they are going to affect the use of polymers in the future?