2 LITERATURE REVIEW

2.1 POLICY AND LEGISLATIVE CONTEXT

Developing policy and commencing municipal solid waste legislation throughout the 1990s has emphasised the potential importance and benefits of home composting as an effective approach to waste management. This section reviews the role of home composting in waste management within EU/UK policy and legislative context in relation to the main waste disposal options.

2.1.1 Definition of waste

The definition of waste in England and Wales is based on Article 1(a) of the original Framework Directive on Waste 75/442/EEC (CEC, 1975), which states that: *waste shall mean any substance or object which the holder disposes of or is required to dispose of pursuant to the provisions of national law in force*. The same article defines *disposal* as: *the collection, sorting, transport and treatment of waste as well as its storage and tipping above or under ground and the transformation operations necessary for its re-use, recovery or recycling*.

Municipal solid waste (MSW) is defined by the Landfill Directive 1999/31/EC (CEC, 1999) as *waste from households, as well as other waste, which because of its nature or composition, is similar to waste from households*. Local authorities have a duty to collect municipal waste from households. Also included in this category are wastes such as garden wastes and bulky items that local authorities may collect separately and which householders themselves take to civic amenity (CA) sites.

Municipal solid waste management involves the purposeful and systematic control of the generation, collection, transportation, storage, separation, processing, recycling, recovery and disposal of wastes. The primary aim of waste management is the delivery of an efficient, cost-effective service, which protects public health and the environment.

2.1.2 Waste disposal routes

Various options are available for the treatment of either whole MSW or materials separated from it, for recovery/recycling or pre-treatment prior to disposal, and these depend on whether the waste is: (a) bulk collected MSW or (b) source segregated MSW.

2.1.2.1 Options for bulk collected MSW

Landfill

Landfill is the controlled deposit of waste to land with little or no pre-treatment. Often minerals workings and extraction sites are used as landfills, providing a means to restore land. However, where such 'holes in the ground' are not available it is possible to deposit waste onto the ground surface and build up a waste disposal site: i.e. *landraising*.

Landfill is currently the dominant waste management practice in the UK, where more than 85 % of household waste is disposed of by landfilling (DETR/WO, 2000). A favourable geology (e.g. clay) in many areas of the country, combined with an active minerals extraction industry, has maintained the low cost of landfilling, encouraging it as the predominant waste disposal option. If properly conducted, controlled and monitored, landfilling is an acceptable and economic method of waste disposal in the UK.

However, there are potential public health and environmental implications associated with landfilling biodegradable waste. Some landfill sites have problems with uncontrolled leakages, litter, odour, and toxic leachate, which have the potential to contaminate surrounding land and groundwater. Landfill gas, a mixture of methane (CH_4) and carbon dioxide (CO_2), is produced from the breakdown of biodegradable waste in the landfill. Landfills are now recognised as the UK's largest man-made source of CH_4 release to the atmosphere (DTI, 1998), which contributes significantly towards global warming. Also, subsidence due to organic matter decay makes landfill sites physically unstable. Importantly, undue reliance on disposal to landfill has inherent risks including missing opportunities for recovering value from waste and being too inflexible to meet changing needs (DETR/WO, 2000). Therefore, alternative disposal routes are being considered to achieve more sustainable solutions to waste management.

Incineration

Incineration is the most widely practised alternative to landfilling and options include mass-burn combustion of bulk MSW under controlled conditions with and without energy recovery (as electricity only and combined heat and power (CHP), refuse-derived fuel combustion and pyrolysis and gasification, where bulk MSW is burnt with little or no pre-treatment.

Mechanical biological treatment (MBT)

Mechanical biological treatment (MBT) is a pre-treatment option for landfilling. Raw MSW, or residual wastes enriched in putrescible materials after the removal of dry recyclables, is subjected to a prolonged combination of composting and mechanical digestion processes, which reduce the biodegradable materials to an inert, stabilised compost residue. The compost, which cannot be used in agriculture or horticulture because of its poor quality, is landfilled or used for temporary landfill site cover or restoration.

2.1.2.2 Options for source segregated MSW

Composting

Composting is conventionally defined as the autothermic and thermophilic biological decomposition of separately collected biowaste in the presence of oxygen and under controlled conditions by the action of micro- and macro-organisms in order to produce compost (EC, 2001a), which can be beneficially applied to land.

Garden and food wastes are segregated at source and composted, producing a bulk-reduced stabilised humus residue of compost that can be used as a soil conditioner in agriculture or land reclamation or as a growing medium in horticulture (DETR/WO, 1998a). Industrial scale, centralised composting can be undertaken in open heaps that are turned and mixed mechanically (windrows), or alternatively in enclosed vessels with internal mixing and aeration. Composting can also be undertaken at a much smaller-scale and has been a traditional practice amongst home gardeners.

Anaerobic digestion (AD)

Like composting, this option is a biological decomposition process using micro-organisms, but in this case the conversion of wet organic waste (such as sewage sludge) into a relatively stable solid residue (digestate) occurs in the absence of oxygen. The organic feedstock for AD of MSW is generated through mechanical separation of whole refuse and from source separation. During AD, waste is digested in sealed vessels under anaerobic conditions and CH_4-rich biogas is produced and used as a fuel for electricity generation or CHP. The volume-reduced digestate residue is used like compost after a period of aerobic maturation and turning, usually in windrows.

2.1.3 Waste production

In 1999, 106 million t of commercial, industrial and municipal waste was produced in England and Wales (DETR/WO, 2000). However, whilst the total amount of waste produced by households is less than from other sources (household represents approximately 25 % of the total amount of waste generated (Table 2.1)), this waste stream represents a potentially significant environmental problem due to the high biodegradable organic content, which contributes to the pollution risk from landfill disposal (Table 2.2). Municipal solid waste typically contains 35-50 % biodegradable waste i.e. green and kitchen waste. If paper and card are also included then around two-thirds of MSW is organic waste. For example, the National Household Waste Analysis conducted by the Environment Agency indicates that 60 % of collected household waste is biodegradable (EA, 2000). The generation of household waste is also increasing annually at a rate of 3 % (DETR/WO, 1999a) with significant practical and operational implications for the management of this waste stream in future. Indeed, >30 million t of biodegradable waste would potentially require diversion from landfill and/or pre-treatment to comply with the requirements of the Landfill Directive by 2020 (DETR, 2000) if this rate of growth were sustained.

Table 2.1 Current annual waste production and management in England and Wales (DETR, 2000)

Source	Waste production (t x 10^6)	% of total waste production		
		Landfill	Recovery	Recycling/ Composting
Industrial (not construction and demolition waste)	48	47	45	39
Commercial waste	30	66	33	29
Municipal waste	28	83	17	9

Table 2.2 Household Waste Components (DETR, 1997)

Waste fraction	Proportion of total household waste stream (%)
Paper	30.7
Plastic Film	4.6
Dense Plastics	3.4
Textiles	3.3
Miscellaneous Combustibles	5.2
Miscellaneous Non-Combustibles	2.5
Glass	7.9
Putrescibles (kitchen waste)	22.5
Ferrous Metal	7.5
Non-ferrous Metal	1.2
Fines (<10 mm)	11.2

2.1.4 Factors influencing the introduction of alternative options to landfill

There are a number of principal global, European and national policy drivers that put pressure on local authorities, as the main group responsible for household waste collection and disposal, to reduce reliance on landfill and to develop more sustainable waste management practices. These drivers include:

- Sustainable development; a process, which culminated in the 1992 Earth Summit at Rio (UNCED, 1992);
- The European 5th Action Programme for the Environment (CEC, 1993), which requires Governments to produce national waste management strategies and set targets for waste reduction and recovery;
- The EU Packaging and Landfill Directives (CEC, 1994; CEC, 1999) will require alternatives to landfill disposal and set mandatory targets for the reduction of packaging and biodegradable waste by landfilling; and
- The UK Government actions to encourage recycling including: *This Common Inheritance* (DETR, 1990), *Waste 2000 Strategy* (DETR/WO, 2000) and *Waste Not, Want Not* (Strategy Unit, 2002),

2.1.4.1 Landfill Directive

Directive 1999/31/EC on the landfill of waste (CEC, 1999) requires European Member States to take action on two levels to:

i. Limit the use of landfill to ensure disposal of regulated amounts of biodegradable municipal waste by the target dates as stipulated in Article 5 of the Directive.
ii. Develop and encourage alternatives to landfill disposal and particularly encourage initiatives, which minimise biodegradable municipal waste production.

Specifically, the obligations in Article 5 of the Landfill Directive require that:

- by 2006, biodegradable municipal waste going to landfills must be reduced to 75 % of the total amount (by weight) of biodegradable municipal waste produced in 1995 (i.e a reduction of 25 % compared to 1995);
- by 2009, biodegradable municipal waste going to landfills must be reduced to 50 % of the total amount (by weight) of biodegradable waste produced in 1995 (i.e a reduction of 50 % compared to 1995);
- by 2016, biodegradable municipal waste going to landfills must be reduced to 35 % of the total amount (by weight) of biodegradable waste produced in 1995 (i.e. a reduction of 65 % compared to 1995).

The UK and other Member States depositing more than 80 % of their collected municipal waste in landfills may postpone attaining these targets by a period not exceeding four years. Therefore, the latest acceptable dates for introducing the staged reductions in landfilling biodegradable municipal waste in the UK are 2010, 2013 and 2020.

2.1.5 UK waste management policy

Over the past 25 years, waste legislation in England and Wales has developed with evolving European legislation. National policy on waste management has only gained a degree of transparency and structure since the publication of the Government's White Paper on the Environment in September 1990 - "*This Common Inheritance*" (DETR, 1990), which introduced the general approach that the administration intended to follow towards improved environmental protection.

In 1995, the Government introduced legislation establishing the Environment Agency as a body to regulate, among other things, the management and disposal of waste in

England and Wales. This legislation (the 1995 Environmental Protection Act (SI, 1995)) also amended existing legislation (including the 1990 Environmental Protection Act (SI, 1990)) to rationalise the requirements to plan effectively for waste, including the preparation of a national waste strategy.

2.1.5.1 Waste management hierarchy

A White Paper on waste management - *Making Waste Work* (DETR, 1995) set out a number of strategies for improving the performance on waste for England and Wales. This proposed the concept of a 'hierarchy of waste management', originally introduced in the EU Directives 75/442/EEC and 91/156/EEC on waste (CEC, 1975; CEC 1991). The Waste Management hierarchy provides the main conceptual policy framework within which sustainable waste management decisions are taken and the most to the least favoured options for managing waste are listed as follows:

(1) REDUCTION - the most effective environmental solution is often to reduce the generation of waste.
(2) RE-USE – products and materials can sometimes be used again, for the same or a different purpose.
(3) RECOVERY – value can often be recovered from waste: (i) Materials recycling, (ii) Composting, (iii) Energy recovery
(4) DISPOSAL – only if none of the above offer an appropriate solution should waste be disposed of.

The overall objective is for waste management practices to move up the hierarchy with disposal representing the least favoured option and recovery, re-use or minimisation being the most favoured options, where they are possible or practicable to implement, thus managing waste in a sustainable way.

2.1.5.2 Approach to sustainable waste management

Local authorities must achieve sustainable waste management by balancing the costs of waste management with the environmental improvements achieved by an appropriate waste management option, which may be selected from the available options using the Best Practicable Environmental Option (BPEO) method (RCEP, 1988). 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 selection process must also consider the Proximity Principle, which stipulates that waste should generally be disposed of as near to its place of origin as possible to minimise trans-boundary shipment of waste and the environmental impacts associated with its transportation.

2.1.5.3 Landfill Tax

The Landfill Tax was introduced in October 1996 (SI, 1996) to increase the price of waste disposal to landfill to reflect its environmental impact, and by applying the polluter pays principle (OECD, 1975), to promote more sustainable waste management *via* waste minimisation, re-use and recycling. Originally levied at £7 t^{-1} (£2 t^{-1} for inert waste), the levy was increased to £10 t^{-1} in 1999 and subsequently by £1 t^{-1} per y as an economic means of implementing the Landfill Directive. The staged increases in the Landfill Tax will bring the standard rate of tax to £15 t^{-1} by 2004 and Government has recently announced its intention to increase the rate to £18 t^{-1} from April 2004.

2.1.6 Composting as a waste management option

Composting is receiving considerable attention as a potential method of reducing the disposal of biodegradable organic matter in landfill. The biodegradable fraction of household waste is putrescible and potentially offensive and cannot be recycled directly without appropriate and effective processing to stabilise the waste to generate an end-product that is amenable to handling, and suitable for re-use. Biologically mediated composting processes can convert putrescible organic waste into soil conditioner products for use in horticulture, agriculture and by home gardeners.

2.1.6.1 EC Working Document – Biological Treatment of Biowaste

In February 2001, the European Commission's Sustainable Development and Policy Support Directorate issued the 2nd draft working document on the *Biological Treatment of Biowaste* (EC, 2001a) to promote discussion concerning this matter between Member States with the intention that this would evolve into proposed EU legislation for the management of biodegradable waste. Part of the driving force behind this initiative is the Landfill Directive 1999/31/EC and its requirement for the pre-treatment of putrescible wastes.

The document deals with the biological processing of biowaste and proposes a hierarchy for the management of Biodegradable Municipal Solid Waste (BMSW) that places composting of separately collected BMSW above both MBT and the use of BMSW for generating energy. The document encourages home, community and on-site composting activities, and urges local authorities to compost green waste from within the community.

In addition, the document covers the following topics: setting up general guidelines on source separation of biowaste; permit and operation requirements for composting, anaerobic digestion, and mechanical-biological pre-treatment facilities; use of compost/digestate, and stabilized residual MSW; labelling and shipment of compost/digestate, and stabilized biowaste; environmental quality classes of compost/digestate, and stabilized biowaste; analytical methods for compost/digestate, and stabilized biowaste; and general requirements for the use of biogas.

2.1.6.2 Composting in the UK

UK Government is attempting to increase the recovery of organic material from MSW by composting and has established the following targets (DETR/WO, 2000) for managing municipal waste to comply with the Landfill Directive:

- to recover value from 40 % of municipal waste by 2005;
- to recover value from 45 % of municipal waste by 2010;
- to recover value from 67 % of municipal waste by 2015.

Recycling and composting of household waste will play a central role in achieving the targets for the recovery of municipal waste and specific targets for these activities are to (DETR/WO, 2000):

- recycle or compost at least 25 % of household waste by 2005;
- recycle or compost at least 30 % of household waste by 2010;
- recycle or compost at least 33 % of household waste by 2015.

Current levels of recycling and composting activities will need to expand dramatically to meet these targets. According to recent statistics the rate of household waste recycling and composting in England increased from 8.8 % in 1998/99 to 10.3 % in 1999/00 (DEFRA, 2001), comprising approximately 7.7 % from recycling and 2.6 % from large-scale composting. In 2000/01, household waste recycling increased to 11.2 % and in 2001/02 it was 12.4 % of all household waste generated in England and 3.2 % and 3.7 % of the waste produced was composted centrally, in each of these years, respectively.

2.1.6.3 Is composting a sustainable option?

Composting is ranked favourably as a waste treatment process in the hierarchy of waste (CEC, 1975; CEC 1991). Although 'Recycling' is placed above 'Composting' recycling is not necessarily the preferable waste management solution. Marginal environmental benefits have been shown to decline as the overloading of materials for recycling increases; and the largest environmental benefits are derived from recycling metals, particularly non-ferrous metals. The benefits from recycling rigid plastics are less advantageous than for metals whereas recycling plastic film leads to net environmental costs. Life-cycle analysis of waste paper management practices shows that the use of waste paper for energy recovery has reduced environmental impact and is the preferred option compared to paper recycling (Leach *et al*., 1997).

Incineration of biodegradable wastes raises a considerable number of waste management and economical problems - such as the acceptance of incinerators by the population, and concerns about emissions and discharges, characteristic of older generation incinerators. It is a costly option in that local authorities are obliged to payback waste contractors over a 20/25 years period and it is usually necessary to feed all waste streams into them to satisfy economic feasibility, thus also potentially limiting future opportunities for recycling.

Composting and recycling organic wastes as soil amendments offers a practical alternative to landfill disposal of BMSW. Composted biowastes, including BMSW, have significant benefit as soil improvers and for correcting declining organic matter in soils, caused by intensive cultivation practices and climatic conditions. In its Soil Protection Communication (EC, 2001b), DG Environment considered that the decline in organic matter content of European soils was a matter of serious concern. In England and Wales, the proportion of agricultural soils containing <3.6 % of organic matter (which is considered a tentative minimum threshold value for fertile soil) has increased by approximately 25 % in the period 1979-81 to 1995. The declining organic matter status is identified in the Draft Soil Protection Strategy for England (DETR/WO, 2001) as a key issue for the sustainable management of soil due to the important implications for the physical condition of agricultural soils. Consequently, from a soil quality prespective, there is sound justification to support composting of biowastes for land application and soil improvement.

However, whilst composting receives general support as an environmentally acceptable approach to managing BMSW, it has been the waste management option least familiar to those engaged in the waste management industry (ESART, 2001), although the technology and experience to manage this waste stream effectively has improved siginificantly recently.

2.1.6.4 Composting options

Composting can be carried out at various scales although the biological process of decomposition operating at the different scales of industrial composting systems are the same. However, the methods and approaches used to control the process depend on the materials being composted and the desired rate of decomposition.

At centralised composting sites, materials are brought for composting. They may arrive as mixtures of different materials or will be mixed/combined on site as part of the process. The composted material may be distributed off site and/or be utilised on site (TCA, 2001).

On-farm sites operate at a small scale and are exempt from waste management licensing. They are located on farms and may compost a mixture of material brought to the site and material produced on site. Material produced by on-farm composting is usually utilised on site (TCA, 2001).

Community composting schemes also usually operate at a small scale, exempt from waste management licensing. Sites are operated by community groups or other ‘not for profit’ organisations, and material for composting is usually collected within the local vicinity (TCA, 2001).

An increasing number of local authorities in the UK have established centralised composting schemes to compost waste produced from municipal parks and gardens, from separate household collection schemes and from civic amenity (CA) sites. There are also a number of voluntary groups establishing community-composting schemes to collect and compost organic material on a co-operative basis. For example, the Devon Community Composting Network consists of a small fleet of mobile chippers to encourage and support local composting activities (DETR/WO, 2000).

2.1.6.5 Large-scale vs. small-scale composting

Centralised composting of sorted or unsorted organic waste follows a complex sequence of activities involving collection, transport, processing, marketing and distribution before final end-use (Figure 2.1). Open-air windrows are the most widely adopted method of centralised composting putrescible solid waste because they offer a practicable and economic approach to composting biowaste. However, siting open-air windrow facilities in urban areas, close to where the waste is generated, can lead to public objections about offensive odour emissions, which are difficult to control in practice, even from a well-managed operation. Another major barrier to the development of centralised composting facilities is the uncertainty about the markets for composted waste products and how to market these to consumers (TCA, 1999a). The virtual absence of source segregation of mixed organic waste in the UK impairs composting of household waste and centralised mechanical separation of unsorted refuse for composting is technologically complex and expensive. Furthermore, early attempts to produce compost from mechanically sorted refuse were unsuccessful due to significant amounts of inert contamination and elevated concentrations of potentially toxic elements (PTEs) compared with composted source segregated waste. Low-grade products, visibly contaminated with inert matter, have negligible market potential and value and may only have utility as a cover material for landfill. However, new separation technologies could offer opportunities to develop composts suitable for general land application from unsorted mixed refuse and this is an area warranting further investigation and research.

A major constraint to the expansion of composting of household waste was imposed on the waste management industry through the 1999 Animal By-Products Order (ABPO) (SI 1999/646) and the 2001 Amendment. This legislation effectively prohibited the use on land of composted catering waste containing meat or the products of animal origin, or which comes from premises handling meat or products of animal origin, including household kitchen waste. This action was taken by the UK Government because infected meat in catering waste was thought to be the origin of the Foot-and-Mouth outbreak in 2001 and the Classical Swine Fever outbreak in 2000, and in recognition that animal byproducts may also be a source of other types of infectious disease, that could be spread by scavenging wild animals and birds.

A new European Regulation (CEC, 2002) controlling the disposal of animal byproducts has recently come into force permitting the composting and land use of catering waste containing meat and low-risk animal byproducts. Although not a compulsory requirement, the Regulation provides treatment standards for the composting of catering waste for land spreading requiring a minimum temperature of 70 ^{o}C for 1 h in a closed vessel. In the UK, DEFRA commissioned a risk assessment (Gale, 2002) to examine the potential risks to public and animal health from composting catering waste containing meat. This concluded that composting of catering waste containing meat could be done safely provided that certain minimum treatment standards were applied. This lead to the introduction of a two stage controlled composting process. The first stage is enclosed and minimum time-temperature conditions apply to both stages, or alternatively, the second stage is unnecessary if the raw material is meat excluded catering waste. Revision of the ABPO is proposed in response to the outcome of the risk assessment and also in recognition that composting catering waste has an important contribution to achieving the reduction in biodegradable waste disposal required by the Landfill Directive (CEC, 1999), and increased recycling targets set by UK Government. Whilst the revised controls aim to increase flexibility by permitting the use of composted kitchen/catering waste on land, they will inevitably increase costs and may limit the economic and practical feasibility of centralised composting of household waste to produce marketable end-products. This may further restrict the ability of the Waste Management sector to achieve the targets placed on it for increased composting of household waste. In addition to the constraints on composting kitchen/catering waste, new composting facilities are subjected to an ‘exclusion distance’ between the site boundary and any sensitive receptor to minimise airborne risk from bioaerosol emissions (TCA, 2004), thus adding to the list of challenges facing the large-scale industry sector.

2.1.6.6 Home composting

An alternative, complementary approach to centralised composting is to treat biodegradable waste at the point of origin and most local authorities in the UK have established home composting schemes to encourage individual homeowners to compost their own organic waste. One of the principal advantages of composting waste in the community by individual homeowners is that the point of waste generation is also the point of disposal since the composted end-product is used directly by the producer (Figure 2.2).

Organic residues composted in private gardens do not accumulate as wastes and this strategy has the potential to:

- decrease the amount of waste collected at the kerbside that enters the waste stream;
- reduce the amount of biodegradable material entering landfills that is responsible for the generation of greenhouse gases and ammonia in landfill leachates;
- decrease the production of potentially toxic leachates at landfill sites reducing the risk of river, surface and ground water contamination;
- conserve landfill void space extending the life of existing landfill sites (in some parts of the UK voids could be filled within 20 years at present rates of disposal);
- produce fuel and energy savings by reducing the transportation of waste;
- reduce environmental impacts of vehicle pollution;
- provide an educational role and raise public awareness of waste minimisation issues;

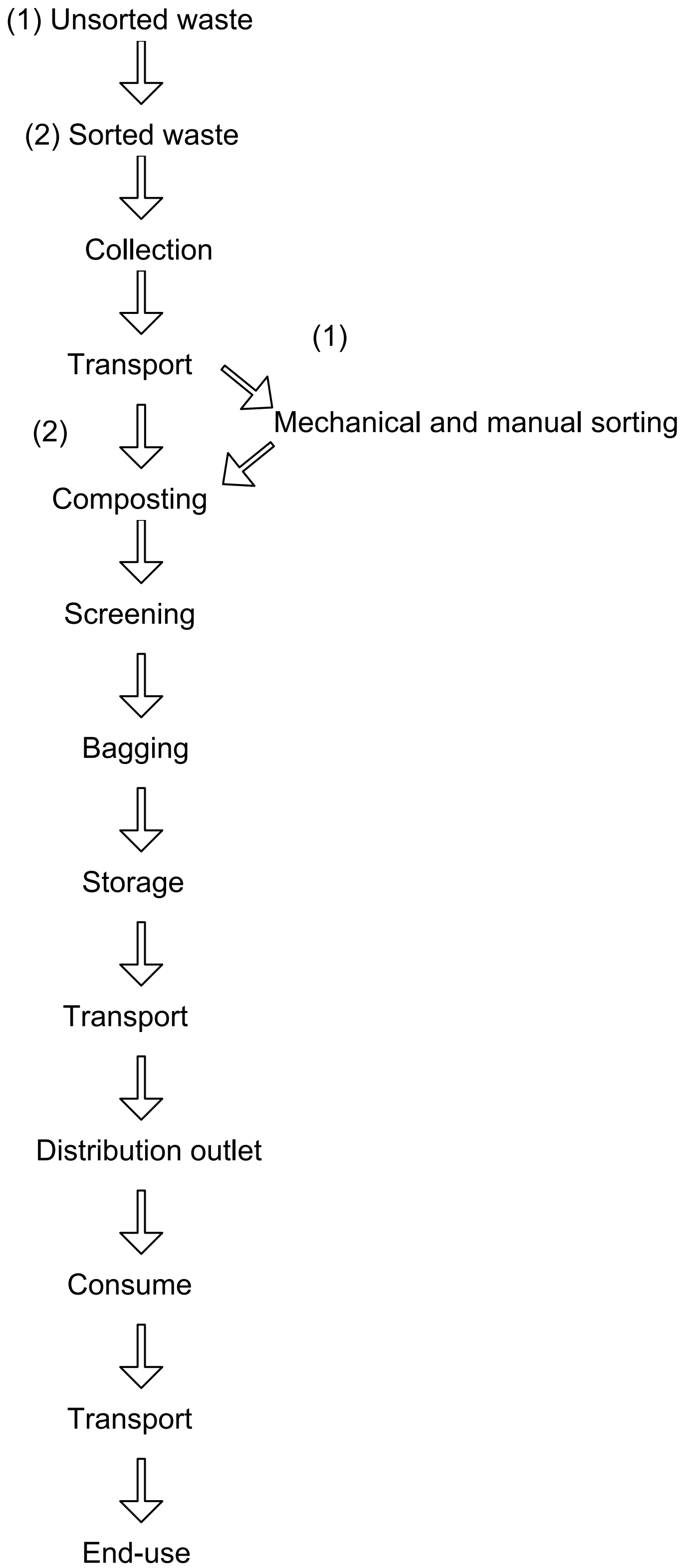

Figure 2.1 Linear pathway of compost production from household waste by centralised composting

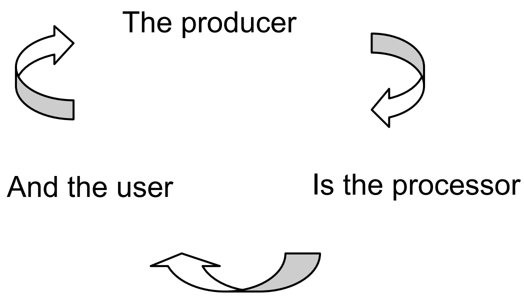

Figure 2.2 The cycle of production, processing and use of biodegradable household waste by home composting

Developing HC as part of an overall waste management strategy is a relatively new concept and some local authorities are encouraging homeowners with private gardens to compost kitchen and garden waste by, for example, providing subsidised home compost bins. Some local authorities raise the profile of composting at home by organising public compost fairs, workshops and meetings to offer advice on home composting kitchen and garden waste and to exchange experience and expertise on composting. A recommendation of the Composting Development Group (DETR, 1998a) was that the profile of HC should be raised by increased media coverage.

Home composting is not affected by the major operational, marketing and economic difficulties and constraints that limit centralised, large-scale composting operations. It provides the householder with the opportunity and incentive to take responsibility for their own organic waste and potentially offers an effective method of diverting organic matter from landfill. It is also the lowest cost option for reducing the amount of waste produced at source. The uniqueness of HC for household waste management is apparent in that it is the only means by which the producer can be the processor and the end-user of the recycled product. In addition, it may also reduce the transport and disposal of garden waste at CA sites.

Home composting has many potential advantages for managing biodegradable organic wastes, but it is also potentially vulnerable to a number of important constraints. For example, HC is dependent on voluntary participation and is not under the direct control or management of the local authority. Participation depends on the willingness and attitude of homeowners and is influenced by socio-economic and demographic factors. Access to a garden is a basic requirement to produce compost by homeowners for garden use, which will rely upon the effective management of the home compost system. Therefore, certain types of dwelling such as flats and apartments are unsuitable for home composting activities. Of those that could technically participate, not all householders may have the necessary motivation. Provided that these criteria can be satisfied, home composting has the potential to contribute significantly to the rates of biodegradable waste diversion as an integral part of an overall waste management plan.

Homeowners wishing to compost their own kitchen waste on their own compost heap are exempt from the animal byproducts legislation, provided they do not keep pigs, ruminants or poultry on the premises. However, the disposal of meat scraps in garden compost heaps is not recommended (DEFRA, 2002). Where poultry are kept, composting should be done in a closed container or compost bin. However, there will be a statutory ban on composting kitchen waste on any premises where ruminants or pigs are kept, including domestic properties (DEFRA, 2002).

2.1.7 Summary

Home composting is clearly in line with the EU and UK Government's key waste management strategy to divert BMSW from landfill disposal. Encouraging homeowners to participate in HC schemes has major potential advantages in providing a low cost approach to waste management and facilitating the sustainable recycling of biodegradable organic waste.

2.2 EXPERIENCE WITH COMPOSTING

2.2.1 Composting practice in EU countries

The treatment of waste in Europe is dominated by landfill and 60 % of waste is currently disposed of by this method, 10 - 15 % is incinerated, 12 % recycled and a further 12 % is composted (EC, 1997). However, waste management practices and landfilling vary considerably according to local conditions and the recycling or incineration policies of individual Member States. Thus, landfilling for instance is as high as 78 % in the UK (DEFRA, 2001), but is much lower in other Member States.

The production of the highest quality grades of compost from household refuse requires separation at source, i.e. the degradable portion of the waste (food/kitchen waste and garden waste) must be collected separately. Approximately 60 million t of organic household waste and green wastes are potentially available for composting in the EU. If all of this were to be composted, 30 million t y^{-1} of product would be produced each year, which contrasts sharply with the 4 million t y^{-1} of compost that are currently produced in the EU. In the UK, 460,000 ha of arable land (6.6% of total available arable land) would be required to receive the theoretical maximum quantity of compost that could be produced, at an application rate of 10 t ha^{-1} y^{-1} (EC, 1997).

2.2.1.1 Large-scale composting in the EU

Many communities across Europe collect organic wastes from households for organic waste treatment, although the coverage of schemes varies significantly between countries. Several Member States recover significantly more organic material by composting than the UK, notably Austria, Belgian, Denmark and The Netherlands (Table 2.3). This places the UK seventh in the EU in terms of the total quantity of organic waste composted, and ninth in terms of the percentage of organic waste composted (3.4%).

European countries with the highest composting rates appear to be affected by three main drivers: (1) the cost of landfill may be very high (e.g. The Netherlands); (2) there is a high demand for compost, almost regardless of quality (e.g. Spain) and; (3), countries with high landfill costs have also introduced legislation requiring source segregation of household waste. Spain, Portugal, Italy and France have very little collection of source-segregated organic household waste, but compost more waste than in the UK, due to the composting of mixed household waste with mechanical separation of contaminants, which are extracted at the plant. Mixed refuse composting plants represent about 14 % of current European capacity, predominantly in these four countries (EC, 1997).

2.3.2.2 Home composting in the EU

Home composting is being promoted in a number of European countries (e.g. Italy, Belgium and Finland) and data on the extent of this activity is shown in Table 2.4, although no data are available indicating HC activity at the EU level.

Table 2.3 Recoverable and composted amounts of separately collected organic wastes in the EU (EC, 1997)

EU member state	Recoverable organic waste (x1000 ty^{-1})	Home composted and separately collected and treated organic waste		Compost production from separately collected organic waste (x1000 ty^{-1})
		(x1000 ty^{-1})	Recovery rate (%)	
Austria	2,200	1,100	50	500
Belgium	1,670	320	19	160
Denmark	900	500	55	250
Finland	700	70	10	30
France	14,500	400	3	150
Germany	9,000	4,000	45	2,000
Greece	1,650	0	0	0
Ireland	350	0	0	0
Italy	9,000	200	2	100
Luxembourg	50	7	14	3
The Netherlands	2,000	1,800	90	650
Portugal	1,200	0	0	0
Spain	6,600	0	0	0
England/Wales	8,000	300	4	150
Scotland	1,000	14	1	7
N. Ireland	240	3	1	2
Sweden	1,500	250	16	100
Total for EU	**60,560**	**8,964**	**15**	**4,102**

Table 2.4 Home Composting in EU Member States

Country	Home composting activity
Austria(1)	280,000 t in 1994 (estimated); 60 % of kitchen and garden waste
Denmark(1)	20,000 t in 1995; 4 % or organic household waste
Ireland(1)	8 pilot projects on home composting started in 1995 involving 800 households
Italy(2)	Participation rates of 10 to 77 % achieved in cases where tax savings of 20 to 30 % were given in Northern Italy
Luxembourg(1)	29 % of households involved in home composting in 1992
Sweden(1)	50,000 t of kitchen and green waste home composted (40-95% of households compost garden waste and 10 % compost food waste)

Source: (1)EC (1997) and (2)Favoino (2000)

2.2.2 Composting in the UK

Historically, the UK has relied on landfill for disposal of MSW due to its availability and low operational costs and this limited the development of more expensive options for waste treatment and recovery, including composting. Furthermore, the demand for waste-derived compost has been uncertain and in particular due to competition from other types of organic waste such as spent compost from the extensive mushroom industry, and from sewage sludge, which is usually supplied and spread on land free-of-charge to farmers by the Water Industry. In addition, the agriculture sector, which is identified a principal market for waste-derived composts, is familiar with using relatively inexpensive chemical fertilisers that provide predictable and consistent crop responses, whereas the direct economic benefits of applied composts are less well defined.

Composting is practised at different scales and many technologies and systems are commercially available for centralised composting of wastes. Currently, the main process type adopted in the UK is open-air windrow turning, as this represents a low cost option compared to other more technological developed invessel methods or aerated static piles. In 1999, 88 % of the waste composted in the UK was by open-air mechanically turned windrow (Slater *et al.*, 2001) and in 2001/02, 79 % of waste was processed in turned windrows (Davies, 2003). The approximate cost of composting in windrow systems is £10-15 t^{-1} of feedstock and is £20-30 t^{-1} by invessel systems (Hogg, 2002a). However, open-air windrows are potentially more susceptible to odour and complaints from the general public as well as bioaerosol emissions during turning operations compared to other methods, which are enclosed or not mixed during the initial active composting phase. Invessel composting takes place in a sealed container where the environment can be carefully controlled and optimised for stabilisation and sanitisation of the product and allow gas scrubbing to prevent odour emissions and containment of bioaerosols.

Currently, the UK composting industry is in a state of expansion and the number of composting facilities and amount of waste processed has increased significantly. In 1999, an estimated 833,044 t of waste was composted in the UK (Slater *et al.*, 2001) at 197 sites. There were 618,517 t of MSW composted, of which 80 % (493,520 t) was household waste and 20 % (124,997 t) was non-household waste. Approximately, 91 % of household waste composted was garden waste from bring sites, and 9 % was collected from the kerbside (Slater *et al.*, 2001). In 2001/02, the total amount of waste composted had approximately doubled to 1,663,852 t, of which 72.3 % was municipal household waste (Davies, 2003). This was mostly (86 %) garden waste taken to civic amenity sites, with small amounts of garden waste only (9.5 %), and garden and kitchen waste, from kerbside collection (<4 %). Of the total amount of waste composted in the UK in 2001/02, a further 8.1 % was non-household municipal waste and 19.6 % was commercial and industrial waste. In 2001/02 the number of composting sites had increased to 218.

Centralised composting facilities handled 92 % of all material composted in the UK at 80 sites in 1999 (representing an increase in the number of centralised facilities of approximately 25 % per annum compared to previous years) and a similar proportion was also processed at 132 sites in 2001 (Table 2.5). On-farm composting at 65 sites represented 8 % of the total waste composted in the UK in 1999, but was expected to increase as it offers farmers diversification opportunities with minimal investment and the product can be used on site (Slater *et al.*, 2001). The number of on-farm composting sites increased to 78 in 2001/02 and the proportion of the total waste composted was maintained at the 8 % level, representing an approximate doubling of capacity in this sector (Davies, 2003). Community composting initiatives represented <1 % of the material composted in 1999 and 2001 (Slater *et al.*, 2001; Davies, 2003) and, due to the small scale of these operations, their role in waste diversion may be relatively limited, although they offer other proximity, social and public awareness benefits (Slater *et al*., 2001).

Table 2.5 Summary of composting activities in the UK in 1998, 1999 and 2001 (Slater *et al.*, 2001; Davies 2003)

Site type	Number of operators		Number of sites		
	1998	1999	1998	1999	2001
Centralised	56	62	59	80	132
On-farm	7	18	11	65	78
Community	11	10	9	52	(93)[(1)]
On-site	9	-	9	-	-
Miscellanous	1	-	1	-	8
Total	84	90	89	197	218

[(1)]Not included in total estimate for 2001

2.2.3 Home composting

Home composted material includes all biodegradable waste composted in a household's garden or allotment, regardless of the type of composting method employed, or whether the composter has been provided by the local authority. However, it is difficult to quantify the actual amounts of waste that are composted by householders. Attempts to estimate the extent and rate of diversion of BMSW from the residual waste stream, and therefore, ultimately from landfill disposal, by home composting are based on semi-quantitative or qualitive indicators such as the numbers of bins sold, compost training programmes, publicity generated, seminars conducted, or other reflections of successful implementation including responses to questionnaires completed by householders (TCA, 2000a). However, these measurements only indicate participation in HC and do not provide quantitative evidence of waste diversion from landfill disposal by HC.

A number of local authorities have attempted to quantify the amount of waste material diverted through HC schemes by asking volunteer residents to record the amount of waste added to their home compost bins (Eco-linc, 2002). It is often assumed implicitly that the amount of biodegradable waste arisings equates with the amount of potentially compostable material. Such analyses are often based on compositional analyses of dustbin wastes (Coggins *et al*., 1997), but do not necessarily account for compostable wastes, which are already recovered or reused or disposed of in some other way.

2.2.3.1 Home composting in the US

Home or backyard composting trials have been carried out throughout North America by county departmental programmes under the Master Composter programme devised by The United States Composting Council (1999). Programme evaluation is structured to measure successful implementation in terms of the intended outcome, and review of results.

Generally, HC programmes exist in communities of various sizes and consist of a great variety of elements in larger communities. However, they have a similar set of basic elements, including brochures, workshops, telephone information lines, and outreach to schools. The average direct budgetary cost of implementing HC programmes nationwide is $12 for every t diverted from landfills, excluding life-cycle cost analysis and the purchase of commercially available compost bins (New York City Department of Sanitation, 1999).

Comparisons of four well documented home/backyard composting programmes in North America are listed in Table 2.6, for Seattle, Orange County, Portland and Monmouth County (City of Seattle, Home Organics Management Survey, 1996; New York City Department of Sanitation, 1999; New York State Energy Research and Development Authority, 1998; Monmouth County Planning Board, 1997; Metropolitan Service District, 1992) and have several principal elements in common. A compositional analysis of aggregated waste (i.e. waste in a truck destined for the landfill) was performed to determine proportions of yard debris, food scraps, and other components in the waste stream. Participation rates and participant behaviour were also assessed. These data were used to estimate an annual diversion rate per household ascending to the locality, which depended on participation rate, population growth or decrease and composting efficiency.

Large variations were apparent in the diversion rates extended by the different programmes (Table 2.6) and can be attributed to the varying trial population size, housing characteristics, programme evaluation method and waste composition analyses. Estimated diversion rates were in the range 77 - 318 kg per household per annum with an average rate of 182 kg per household per annum.

2.2.3.2 Home composting in UK

A recent national survey of composting activity conducted in 1999 (Slater *et al*., 2001) indicated that approximately 75 % of the local authorities that responded were promoting home composting by supplying home composting units. Respondents estimated that they supplied approximately 258,000 composting units, and that prior to 1999 around 600,000 units had been distributed. Around 70 % of units were offered to the public at subsidised costs, 17 % were offered free of charge and 13 % were offered at full cost. (Slater *et al*., 2001)

Local authorities use a variety of methods to communicate and promote HC to the public (Table 2.7). Local media and distribution of leaflets to the public are the most popular methods, and home visits are the least popular (Table 2.7).

Approximately, 40 % of local authorities that promoted home composting had not undertaken any monitoring or assessment of their scheme. Of the 60 % that had undertaken some monitoring, around two-thirds relied on questionnaires completed by householders. However, 14 local authorities, which had previously promoted home composting, had ceased this activity in 1999. Ten respondents cited lack of funds, difficulty in calculating the amount of waste diverted by HC, and focus on kerbside collections for organic waste as reasons for no longer actively promoting HC. Seven local authorities stated that they no longer offered composting units, although they still promoted the principle of home composting (Slater *et al*., 2001).

Table 2.6 US compost programs

Study Program Reference	City of Seattle, Home Organics Management Survey, 1996	New York City Department of Sanitation, 1999	New York State Energy Research and Development Authority, 1998	Monmouth County Planning Board, 1997	Metropolitan Service District, 1992
Study period	1989-1995	Nov 1996-April 1997	1997-1998	March-Nov 1996	1992
Study location	Seattle, Washington	New York City (Bronx, Brooklyn, Queens and Staten Island), New York	Orange County, New York	Borough of Brielle-Monmouth County, New Jersey	Portland Metropolitan District-Oregon
Participation	63,550 citywide	221 volunteers-pilot areas 2,125 non-volunteers	150-pilot area	53-pilot area	110-pilot area
Population	500,000	7,300,000	307,647	510 households	1,200,000
Program description	Master composter hotline, demonstration sites, bin distribution and education	Telephone survey and waste composition study in June 1997	Pre- and post-program questionnaires	3 waste composition studies (March, July and October) before, during and after	Workshop participants, community presentations, visitors to leaf composting clinics, brochures from demonstration sites

Table 2.6 US compost programs, continued

Study Program Reference	City of Seattle, Home Organics Management Survey, 1996	New York City Department of Sanitation, 1999	New York State Energy Research and Development Authority, 1998	Monmouth County Planning Board, 1997	Metropolitan Service District, 1992
Yard waste composting diversion estimate (kg per household y^{-1})	121	59	180	N/A	N/A
Food waste composting diversion estimate (kg per household y^{-1})	77	14	137	44	N/A
Total composting diversion estimate (kg per household y^{-1})	198	73	318	88	232

Table 2.7 Type of communication used to promote home composting (Slater *et al*., 2001)

Types of communication	Number of schemes
Leaflets to householders	168
Local media	155
Roadshows	82
Telephone hotline/advice line	93
Home composting roadshows	82
Through local schools	65
Letters to householders	59
Through community groups	53
Home visits	16

Slater *et al*. (2001) noted that local authorities have no incentive to measure waste diverted to HC due to exclusion of this activity from recycling credit payments and local authority performance indicators intended to monitor the progress towards achieving national objectives for municipal waste (DETR, 1999b). The UK Government published (DETR, 1999c) a formula to estimate the number of households involved in HC and the quantity of waste diverted from landfill disposal (Figure 2.3) assuming a default value for the amount of waste composted by participating households of 100 kg per household per y. However, applying this approach proved to be difficult in practice because local authorities were unable provide accurate information on participation rates in HC. Consequently, waste diverted by HC is not currently eligible for recycling credit payments because of the uncertainty regarding the actual effectiveness of HC at waste diversion. Home composting is therefore considered as a method of waste minimisation.

The amount of waste that is composted at home and is therefore diverted from landfill disposal remains a major uncertainty. In addition, data on the amounts of paper and cardboard waste (which comprise the majority fraction of biodegradable MSW) diverted from landfill by HC have not been reported by previous surveys. Whilst all putrescible wastes are biodegradable, not all are recommended as feedstocks for HC. Analyses carried out in Luton in 1996 (Coggins *et al*., 1997), using a classification of compostable (uncooked fruit and vegetable items, tealeaves and bags, cut flowers and plants) and non-compostable (cooked food, meat and dairy products) fractions, showed there was approximately 18 % compostable and 3 % non-compostable kitchen waste and approximately 9 % and 2 % compostable and non-compostable garden waste, respectively, in the dustbins sampled (Coggins *et al*., 1997) in relation to the total amount of collected household waste. Variations were also noted between the inner and outer areas of the town. The weekly dustbin weights of compostable wastes were 3.0 kg per household per week of kitchen wastes in inner Luton and 0.4 kg per household per week in outer Luton. The differences were considered to arise because of different purchasing habits and different garden sizes between the two areas.

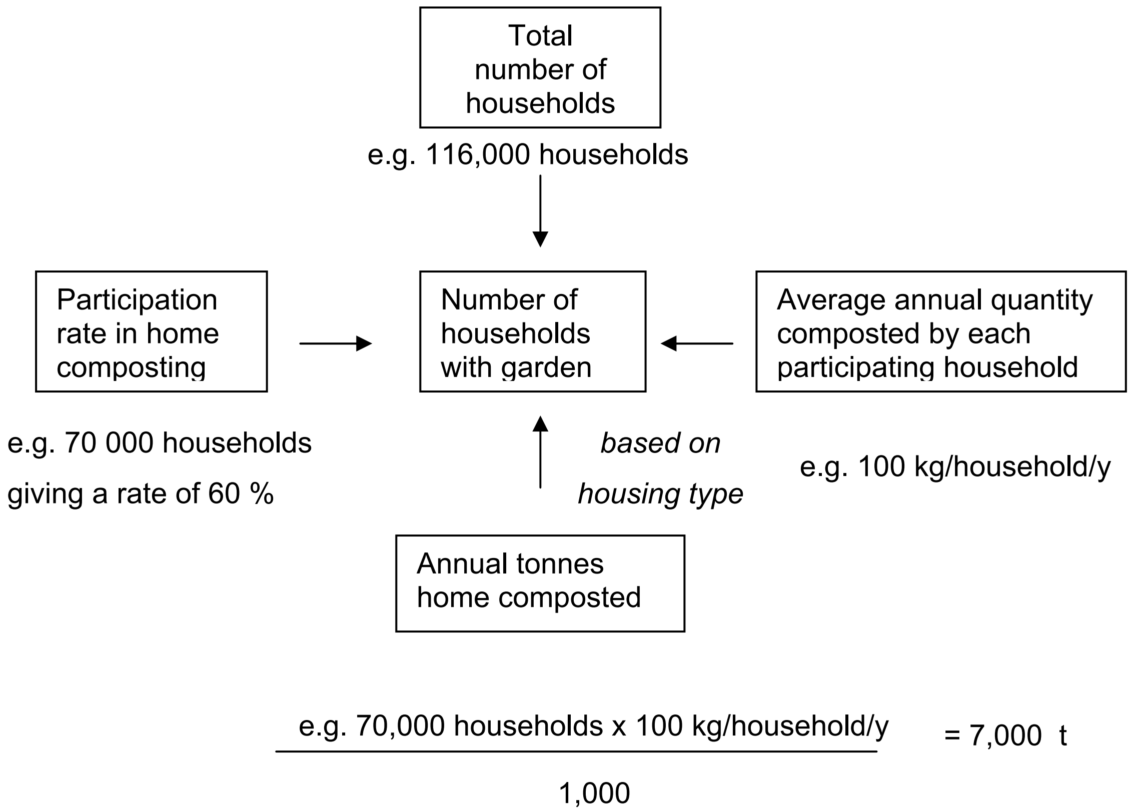

Figure 2.3 Quantity of compost/household (adapted from DETR, 1999c)

A number of recent surveys of public attitudes towards HC have been reported (Table 2.8). This information is useful as it assists waste disposal authorities (WDAs) to target resources at those groups that are most likely to participate in HC activities. A national opinion (NOP) survey of HC (Table 2.8) showed that participation had increased from 29 % in 1997 (DETR, 1998b) to 34 % in 2000 (Burnley and Parfitt, 2000).

Research in waste diversion by HC is very limited. Some local authorities have attempted to quantify waste deposited in compost bins, but the results are not generally available in the public domain. One such study is reported by Fletcher *et al*. (2000) from a survey of 100 households in the Borough of Flyde, Lancashire. The households weighed biodegradable waste inputs to the compost bin during the period Oct 1996-September 1997. The seasonal variation in total waste inputs was in the range 5.5 to 23.5 kg per household per month in February and July 1997, respectively. However, in another study involving 36 participants, Fletcher *et al*. (2001) measured an average total weight addition to 330 l capacity compost bins of 26.5 kg per household per month during the period May-July 1999.

A UK version of the US Master Composter Manual (US Composting Council, 1999) is available to local authorities (HDRA, 2000) and provides information on home composting to householders in training workshops or as a troubleshooting resource when problems in HC are encountered. The manual was intended to increase participation of HC schemes although the extent to which the manual has been implemented has not been measured.

Table 2.8 Comparison of home composting surveys in the UK

Source	Region	Date	No. of households	No. of responses	Uptake of home composting (%)
Onyx NOP Survey (Burnley and Parfitt, 2000)	England & Wales	4-16 February 2000	1755	-	34
HDRA UK Home Composting Survey (HDRA, 2000)	UK local authorities	June 1999	474 local authorities	324 local authorities	5 – 7
Environment Agency Survey (EA, 2000)	20 local authorities in England	July 1997	1048	572	37
Aberdeenshire Council (Roslyn Associates, 1998)	Aberdeenshire	1993 – 1998	746	461	56.8
DETR NOP Survey (DETR, 1998b)	England & Wales	8 - 14 October 1997	1260	365	29

2.2.4 Summary

The conditions influencing waste management in European countries vary considerably to those operating in the UK and, elsewhere, composting is generally much more widely practised as a routine waste management method. Home composting is potentially amongst the most sustainable options available for recycling biodegradable household waste and also reduces peat consumption by home gardeners. However, uncertainty about the effectiveness of this activity at waste diversion, and its exclusion as a performance indicator, reduce incentives for local authorities to support and promote HC as a landfill diversion option.

2.3 RUNNYMEDE BOROUGH COUNCIL

2.3.1 Introduction

Runnymede Borough Council (RBC) was the instigator of the research on HC described in this report, and the practical investigations were focussed on specific refuse collection rounds within the Borough, where waste arisings had been monitored for a number of years. Prior to this study, HC activity had not been monitored in the Borough. However, it was recognised that information was needed to determine the effectiveness of HC as a waste diversion technique to inform decisions on the levels of investment and resources that should be focussed on promoting the activity.

2.3.2 Background

The Borough of Runnymede came into existence as a result of local government reorganisation on 1st April 1974. Residents elect Councillors to serve for a period of four years. For this purpose the Borough is divided into 14 wards (Table 2.9), each returning three councillors, giving a total of 42 elected representatives for 60,014 electorates. The Borough covers 7,800 ha and the resident population in 1998 was 76,399. There are 31,606 homes in the Borough (RBC, 1999).

Table 2.9 Borough Wards in Runnymede (RBC, 1999)

Addlestone Bourneside	Addlestone North
Chertsey Meads	Chertsey St Anns
Chertsey South & Rowtown	Egham
Englefield Green East	Englefield Green West
Foxhills	Hythe
New Haw	Thorpe
Virginia Water	Woodham

2.3.3 Waste inventory

2.3.3.1 Quantities of waste generated

Approximately 38,000 t of waste are generated per year within the Borough of Runnymede and approximately 74 % of the total amount is collected from households. The composition of MSW collected within the Borough is listed in Table 2.10. Only minor variations in quantities of waste generated by door-to-door collection are apparent since 1996 (Table 2.11) and the most recent statistics (2000/2001) suggest there was a small decrease in the amount of waste collected in 2000/01, compared to 1999/2000, but waste arisings have remained relatively static since 1996/97. This is against a national background increase in MSW arisings of 3 % per year (DETR, 1999a). The quantities of waste taken to civic amenity (CA) sites by residents in the Borough is uncertain due to usage of these facilities by individuals from both within and outside the Borough of Runnymede.

2.3.3.2 Composition of wastes generated

There is no specific information about the composition of household waste generated within Runnymede. However, data are available for the composition of household waste within Surrey County Council (SCC, 1991a). These statistics indicate that the putrescible fraction represents 25 % of the total waste stream and 29 % of the waste consists of paper and board (Table 2.10), in line with national statisitics on waste composition analysis (Table 2.2). Both of these waste types are potentially suitable for HC. Therefore, approximately 50 % of the door-to-door collection in the Borough is potentially compostable, equivalent to approximately14,000 t y^{-1} of biodegradable waste. Approximately, 380 kg of waste is generated per head of population annually (RBC, 2002).

Table 2.10 Composition of wastes generated in RBC (SCC, 1991)

Waste Type	Proportion of total waste collected (%)
Paper and board	29
Putrescible material	25
Dust and cinder	12
Glass	10
Metal	8
Plastic	7
Textiles	4
Other	5

Table 2.11 Quantities of waste generated within the Borough of Runnymede (pers. Com. Dennis Speight, Head of Environmental Protection, RBC)

Source	Waste collected (t y^{-1})				
	1996/97	1997/98	1998/99	1999/00	2000/201
Door to door collection	28842	28766	27854	29229	28766
Civic Amenity Site	-	-	6846	-	-
Recycling banks	1345	1393	1391	1457	1696
Other sources (eg street cleansing)	1430	1480	1750	1790	1820

2.3.4 Current waste collection and disposal practices

2.3.4.1 Collection methods

Runnymede Borough Council is the Waste Collection Authority (WCA) and currently operates a wheeled bin refuse collection service (RBC, 1993), collecting containers from the back door of properties and returning them to the boundary. Wheeled bins were introduced to improve the efficiency of the waste collection service, but this also increased the amount of waste collected by 55 %. The capacity of the wheeled bins (240 l) was more than twice that of traditional dustbins and this discouraged householders from transporting certain materials, such as garden waste, to CA sites for disposal. Householders were also encouraged to place green waste into the wheeled bins and, whilst there is no statistical evidence available, significant seasonal changes in the composition of collected refuse was apparent (pers.com., D. Speight, RBC).

2.3.4.2 Civic amenity site
There is a single CA site operated by Surrey County Council (SCC) situated at Lyne Lane, Lyne. Recycled materials included metals, oil, textiles and CFCs.

2.3.4.3 Waste disposal methods
There are no waste transfer facilities operating within the Borough of Runnymede. However, there are two large landfill sites within the Borough. One of the landfills is licensed for controlled (household and commercial) wastes and is operated by Surrey Waste Management and the other is the Norlands Landfill, Thorpe, owned and operated by Thames Waste Management Ltd. This site accepts a full range of controlled wastes. The local hospital incinerator accepts a small amount of clinical waste collected in the community from dialysis patients, but there are no other incineration facilities in the Borough. There is a large-scale, open-air windrow composting plant for green waste situated in Lyne Lane operated by a commercial waste management contractor. The facility has operated for 10 years, but there is considerable public objection and complaints about malodour emissions from the site.

2.3.4.4 Recycling collection systems
The Council recycles drinks cans and textiles in addition to glass, and waste paper is collected from the Civic Offices for recycling. The cans and paper are sold to merchants and the textile banks are operated by the Humana charity.

2.3.4.5 Bring systems
Bring systems operate by providing the public with banks for depositing recyclable materials. The Council recognises that bring systems alone will not achieve the Government's recycling target of 25 % of household waste by 2005 in the Borough (DETR/WO, 2000).

2.3.4.6 Kerbside collection
Kerbside collection schemes operate using specialist vehicles to collect recyclables from individual households. The door-to-door collection of separated waste fractions is popular with the public and is an effective approach to source segregating household waste (SCC, 1991b). However, the capital costs of the vehicles and sorting station, coupled with the additional revenue costs of collecting and sorting materials, against a background of uncertain and unstable cost recovery and profitability from recycled commodities, have not favoured the introduction of kerbside collections in Runnymede. The Borough recently received financial support for a scheme to introduce kerbside collection and a pilot programme was established in 2003 in the same areas that are the focus of the HC study reported here.

2.3.5 Composting in RBC
The RBC Recycling Plan (RBC, 1993) recognised the potential for waste minimisation by diverting a proportion of household waste and most garden waste from refuse collection towards composting. The Plan stated that a change in policy away from collecting garden refuse in wheeled bins may be required, but the Council was concerned that this could potentially create other environmental problems, such as backyard burning. Opportunities for developing a centralised composting facility were explored with the

Council's refuse collection contractor and the County Council, but there were doubts and uncertainty about the possible markets for the composted product. In addition, the centralised composting site operating within the Borough is also unpopular (section 2.4.4.3) with the public and the Council was reluctant to expand further centralised composting in the Borough.

Runnymede Borough Council embraced the home composting targets outlined in the White Paper *Making Waste Work* (DETR/WO, 1995) and organised a number of campaigns offering subsidised home compost bins to residents during the last 10 y. However, due to the inadequate guidance available on calculating composting rates, RBC were unable to measure the impact of home composting on waste reduction in the Borough. Through discussion with The Norlands Foundation, (the Environmental Body of the local landfill operator, Thames Waste Management Ltd) there was joint interest in establishing a research project to determine the extent of waste diversion achieved by home composting activities. Imperial College London was approached to develop a research programme (designated as the RBC Home Composting Study), with funding from the Landfill Tax Credit Scheme, to quantify the effectiveness and practicability of home composting at diverting biodegradable waste from landfill.

A research programme was developed incorporating a two year monitoring exercise of HC activity by homeowners from three door-to-door collection rounds (designated as the Study Area) in the Chertsey, Hythe and Thorpe areas of RBC (see Figure 2.4). Proprietary compost bins were offered through a leaflet promotion and were distributed to homeowners in the Study Area. Sixty four homeowners were also invited to actively participate in the research investigations designed and managed by IC.

2.3.5.1 RBC best value performance plan

The Local Government Act 1999 (SI, 1999) requires local authorities to produce a Best Value Performance Plan, which compares performance during the year with previous years, and outlines future performance targets.

Improving our Environment is one of five service aims within the RBC Plan (RBC, 2000). Targets are taken from the Council Leader's Annual Position Statement and are conveyed to the Council's staff through the Performance Appraisal Scheme. The 4th Service Target for 2000/01 states that the Council aims to '*meet programme for pilot home composters in conjunction with Norlands Foundation and secure the £30,000 sponsorship. Imperial College London to evaluate and report on effectiveness and usage of composters by 2003/04 and impact on recycling performance.*'

2.3.6 Cost of waste collection

A summary of RBC's expenditure on refuse collection and street cleansing in recent years is shown in Table 2.12 (pers. com. D. Speight, RBC). Expenditure for managing this service will continue to increase. Costs per household of refuse collection and street cleansing since 1997 are also summarised in Tables 2.13 and 2.14, respectively. The cost of waste disposal by landfill is currently £32 t^{-1} of waste including landfill tax (pers.com. D. Speight, RBC).

Table 2.12 Costs (£) of refuse collection and street cleansing in RBC

Activity	97/98	98/99	99/00	00/01	01/02	02/03
Total annual cost (x1000)			1,699	1,738	2,020	2,147
Net cost per household for refuse collection	20.74	22.18	24.17		28.78	
Net cost per head for street cleansing	5.97	6.30	6.48			

2.3.7 Summary

Total door-to-door MSW collection in Runnymede has remained fairly static in recent years, although refuse collection costs per household have risen. Recycling and CA site activity have increased, but there are uncertainties as to the specific quantities of waste arising within the Borough diverted from landfill by these routes since the facilities are used by individuals from within and outside the Borough. Although RBC has offered subsidised compost bins to promote HC in the Borough, the impact of this on waste reduction was uncertain and stimulated interest in establishing a research project to measure the effectiveness of HC at waste diversion.

2.4 COMPOST MANAGEMENT PRACTICES

2.4.1 Introduction

Composting progresses through a sequence of stages that have been described both in general population terms (Bagstam, 1979 and 1978; Faure and; Amner *et al*., 1988; Deschamps, 1991; Macauley *et al*., 1993; Beffa *et al*., 1996) and operationally (Miller *et al*., 1980). The general principles of conventional centralised batch operated composting systems will be reviewed and compared to biological activities in small-scale home composters, where additions of different types and amounts of organic waste occur on a frequent basis.

Composting is conventionally defined as the autothermic and thermophilic biological decomposition of separately collected biowaste in the presence of oxygen and under controlled conditions by the action of micro- and macro-organisms in order to produce compost (EC, 2001a), which can be beneficially applied to land. However, the definition of composting may also be broadened to include cooler aerobic breakdown of bulky wastes in small scale composters, as is the case with small pile composting in the domestic context, and by 'slow-stack' treatment methods, where temperatures are in the psychrophilic (0-20 ºC) to mesophilic (20-45 ºC) ranges.

All composting systems involve a solid-phase organic material, which serves as physical support, gas exchange matrix, source of organic and inorganic nutrients, water, and diverse microbes, sink for metabolic waste products, and thermal insulation (Figure 2.5). The major form of microbial metabolism is aerobic respiration during which microorganisms break down organic matter and produce carbon dioxide, water, heat, and humus, the relatively stable organic end-product. The heat is retained within the matrix, causing self-heating, or a temperature elevation, which is characteristic of the process (Chongrak, 1996).

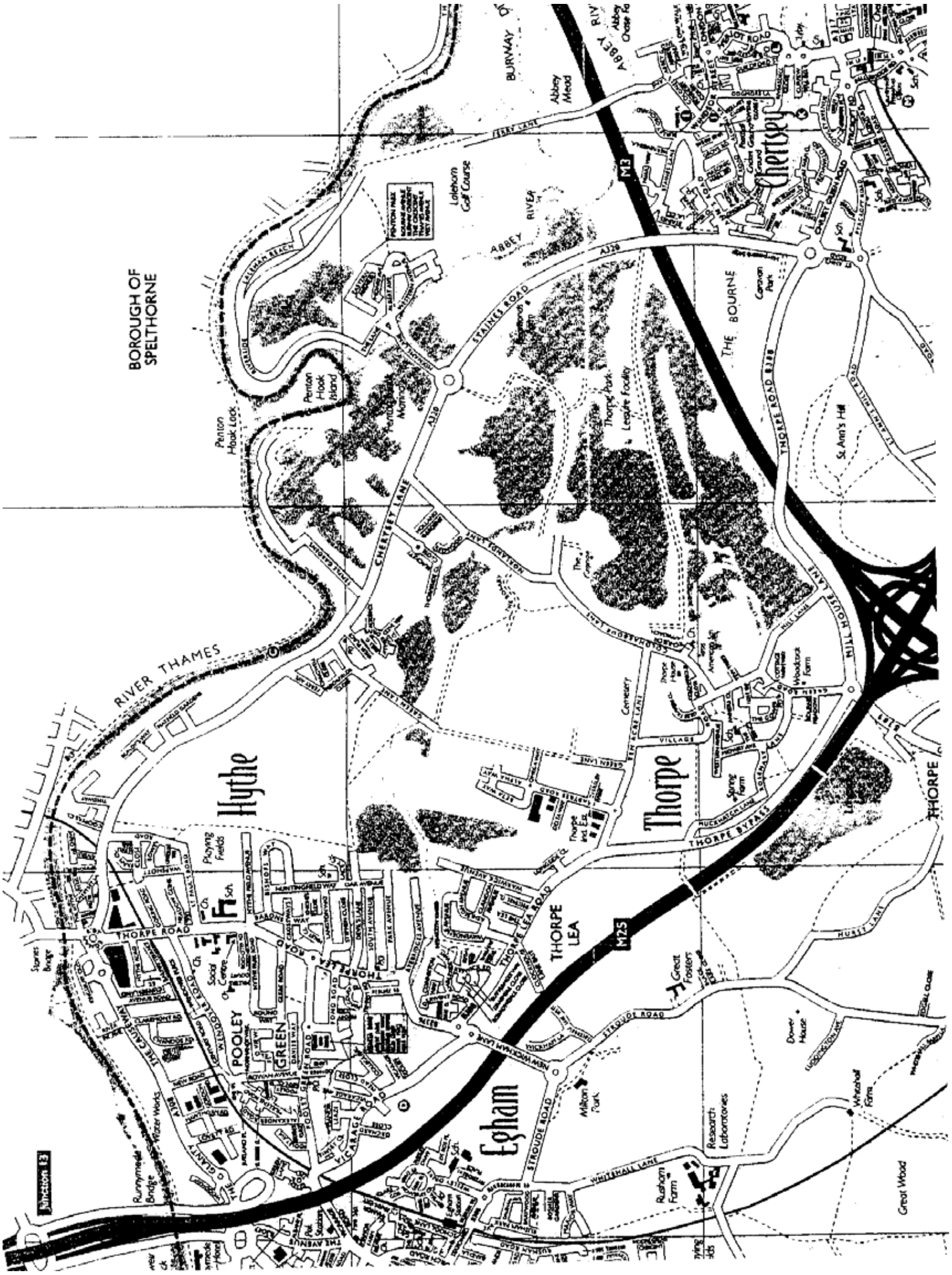

Figure 2.4 **Location of the Home Composting Study Area within the Borough of Runnymede**

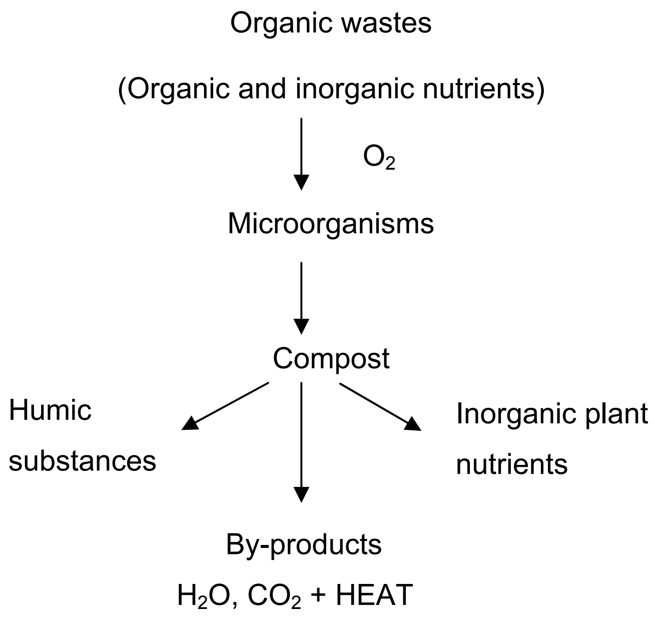

Figure 2.5 Schematic representation of the composting process

Biochemical reactions enable nutrients to be returned as compost in the form of microbial protoplasm and/or organic compounds that break down slowly. The breakdown products are used for cellular metabolism with the formation of biomass, new microorganisms, and the evolution of CO_2.

2.4.2 Microbiological aspects of composting

In general, the composting process is initiated through a successional dominance of microbial populations. Based on microbial activity, the composting process can be divided into four different stages according to temperature patterns (Finstein and Morris, 1975; Strom, 1985). These distinguishable phases are summarised in Table 2.13.

The temperature of the pile increases rapidly above ambient during the initial stages of composting. Mesophilic bacteria (mostly *Bacillus* spp) play a major role in the decomposition of proteins and other carbohydrate compounds (Strom, 1985). In spite of being confined primarily to the outer layers of the compost piles and becoming active only during the latter part of the composting period, thermophilic fungi (*Aspergillus* spp) and actinomycetes (*Streptomyces* spp and *Thermoactinomyces* spp) play an important role in decomposing cellulose, lignins, and other more resistant materials such as complex plant polymers, which are attacked after the readily decomposed materials have been utilized (Biddlestone *et al*., 1987).

As the temperature rises above about 40°C, the mesophilic microorganisms become less competitive and are replaced by others that are thermophilic (heat-tolerant) microorganisms, which accelerate the breakdown of high-energy compounds. Thermophiles become inactive at temperatures greater than 65-70 °C, when only spore-forming bacteria can develop (Finstein *et al*., 1985a) and pathogen destruction occurs within this temperature range (Golueke 1982). As substrates become exhausted, compost temperature gradually decreases and mesophilic microorganisms return for the final phase of "curing" or maturation of the remaining organic matter (Leton *et al*., 1983) and the temperature of the composting materials fall back to ambient (Devisscher, 1987). Transient increases in the temperature may occur after turning, due to the reintroduction of oxygen into the mix. Although there is no definite point at which the 'active' processing stops, the final stages of composting are dominated by members of the actinomycetes, which are characterised by a white or grey appearance on the surface of the heap (Diaz, 1993). In HC, all these phases may be present simultaneously.

Table 2.13 Phases of composting process (Finstein and Morris, 1975; Strom, 1985)

Phase	Microbes	Phase characteristic	Temp °C
LATENT (cryophilic)	Cryophiles/ psychrophiles	Period in which microorganisms acclimatize and colonize environment in the compost heap.	5-10
GROWTH (mesophilic)	Mesophiles	Period during rise of biologically produced heat to mesophilic level. Abundance of substrate ensures that high activity of microorganisms, leading to greater generation of metabolic heat energy, which causes the temperature of the compost pile to rise.	15-45
THERMOPHILIC	Thermophiles	Period during which temperature rises to the highest level. Waste stabilization and pathogen destruction are most effective. Efficiency and speed begin to drop abruptly particularly at temperatures in excess of 70°C as spore-formers begin to lose their vegetative forms and assume spore forms during which little activity takes occurs.	50-70
MATURATION	Mesophiles, psycrophiles, lytic organisms	Temperature decreases to mesophilic and, subsequently, ambient levels. Microbial activity is low and chemical reactions continue to occur making the remaining organic matter more stable and suitable for use with plants. Secondary fermentation takes place slowly and favours humification; that is, the transformation of some complex organics to humic colloids closely associated with minerals (iron, calcium, N, etc.) and finally to humus.	10-30

Composting being a biological process is constrained by the limitations of biological systems. It proceeds at a rate, and to an extent, equal only to those permitted by the genetic traits of the microorganisms under the prevailing conditions. The rate of processing increases with temperature until it exceeds 70 ºC, at which temperature microbial activity is inhibited. Composting kept within the range of 45-55ºC allows the greatest microbial ecological diversity to develop and consequently a more thoroughly stabilised product, while higher temperatures limit the microbial population diversity but hygienise the compost more effectively (McKinley *et al.*, 1986; Suler and Finstein, 1997).

2.4.3 Biochemical reactions

The course of biochemical break down of organic wastes is complex, inducing several intermediates and pathways. The complexity and molecular structure of the substrate are important because they determine the assimibility of the nutrients in the substrate by the various microorganisms. (Goldstein, 1991) and the heat released from the process causes the temperature of decaying waste to increase, and this further increases the rate of decomposition.

The commencement of composting is characterised by an increase in the biomass and activity of indigenous mesophilic microorganisms feeding on simple carbon compounds, soluble sugars and organic acids (De Bertoldi *et al.*, 1983). Easily degradable materials such as carbohydrates and proteins are degraded into smaller monomer units (sugars, amino acids etc) by microorganisms growing on the biodegradable components of the waste (Chongrak, 1996):

The degradation of proteins follows the sequence:
Proteins ⇒ peptides ⇒ amino acids ⇒ ammonium compounds ⇒ bacterial protoplasm and atmospheric N or ammonia.

The degradation of carbohydrates follows the sequence:
Carbohydrates ⇒ simple sugars ⇒ organic acids ⇒ CO_2 + bacterial protoplasm.

The reaction rate decreases as more resistant materials such as plant cells are encountered. Plant cell wall material is composed of three important constituents: cellulose, lignin and hemicellulose. Cellulose is a long chain of glucose molecules, linked to one another repeatedly with β(1-4) glycosidic bonds, which requires little enzymatic action for material degradation. Hemicelluloses are branched polymers of xylose, arabinose, galactose, mannose, and glucose, that form microfibrils with lignin creating a complex web of bonds to provide structural strength, which challenge microbial degradation (Ladisch *et al.*, 1983; Lynch, 1992). Lignin is particularly difficult to biodegrade because it is the most recalcitrant component of the plant cell wall. It is a complex polymer of phenylpropane units, which are cross-linked to each other with a variety of different chemical bonds. The effect of lignin on the bioavailability of other cell wall components is thought to be largely a physical restriction, with lignin molecules reducing the surface area available to enzymatic penetration and activity (Haug, 1993). Therefore, the higher the proportion of lignin the lower the bioavailability of other cell wall constituents. The reinvasion of fungi into the mass from the cooler regions of a compost heap, and an abundance of mesophilic actinomycetes, attack the long chain polysaccharides, hemicelluloses and cellulose, breaking them down into simple sugars that may then be utilised by a wider range of microorganisms.

Microorganisms and invertebrate microfauna decompose organic matter by producing enzymes, which are the biocatalysts of all biochemical reactions. The hydrolysis and subsequent assimilation of polymeric material is a relatively slow process. Hence the rate of heat generation decreases during the latter stages of the composting process, after the easily biodegraded substrates have been exhausted and, consequently, the temperature falls towards ambient. By the action of enzymes on organic matter, microorganisms not only change the substrate composition, but also change the pH of the medium and release heat due to metabolic activity. Enzymes function within certain ranges of temperature and pH, but when these parameters change, a new population of microorganisms is selected producing enzymes that are better adapted to the available substrate and conditions. Thus, microorganisms create the conditions leading to their own destruction, which are then exploited by subsequent microbial populations.

Only a limited number of specialized organisms possess hydrolytic enzymes, but almost all organisms can assimilate the resulting fragments. Low molecular weight, water-soluble materials pass readily through the cell wall and are metabolised by a wide range of non-specialized organisms. High molecular weight polymeric materials cannot pass into the cell and are useless in their natural state as substrates for many organisms (Lester, 1999). Some molecules will either remain partially or completely unchanged at the end of the process depending on the ability of microorganisms to produce the required enzyme for degradation.

Haug (1980a) conceptually summarised the various rate-controlling phenomena occurring during aerobic composting, which include:

1) Release of extracellular hydrolytic enzymes by the cell and transport of enzymes to the surface of the substrate;
2) Hydrolysis of substrate molecules into lower molecular weight, soluble fractions;
3) Diffusion transport of solubilized substrate molecules to the cell;
4) Diffusion transport of substrate into the microbial cell, floc, or mycelia;
5) Bulk transport of O_2 (usually in air) through the voids between particles;
6) Transport of O_2 across the gas-liquid interface and the unmixed regions which lie on either side of such an interface;
7) Diffusion transport of O_2 through the liquid region;
8) Diffusion transport of O_2 into the microbial cell, floc, or mycelia; and
9) Aerobic oxidation of the substrate by biochemical reaction within the organism.

2.4.4 Biological succession

The succession of decomposition is an ecologically dynamic and a complex range of interdependent biological processes carried out by microorganisms and higher animals to accomplish waste stabilization. The temperature conditions and available substrate supply appear to exert the greatest influence in determining the microbial species present in the population at any one time.

The compost pile consists of a complex food web, representing a pyramid with primary, secondary, and tertiary level consumers (2. 6). The base of the pyramid, or energy source, consists of organic matter including plant and animal residues. Initially, organic wastes are decomposed by microorganisms, which are the first-level consumers. The bacterial and fungal biomass generated in the initial phases of composting can become food for a succession of higher organisms, which may be associated with the process (Trautmann, 2002).

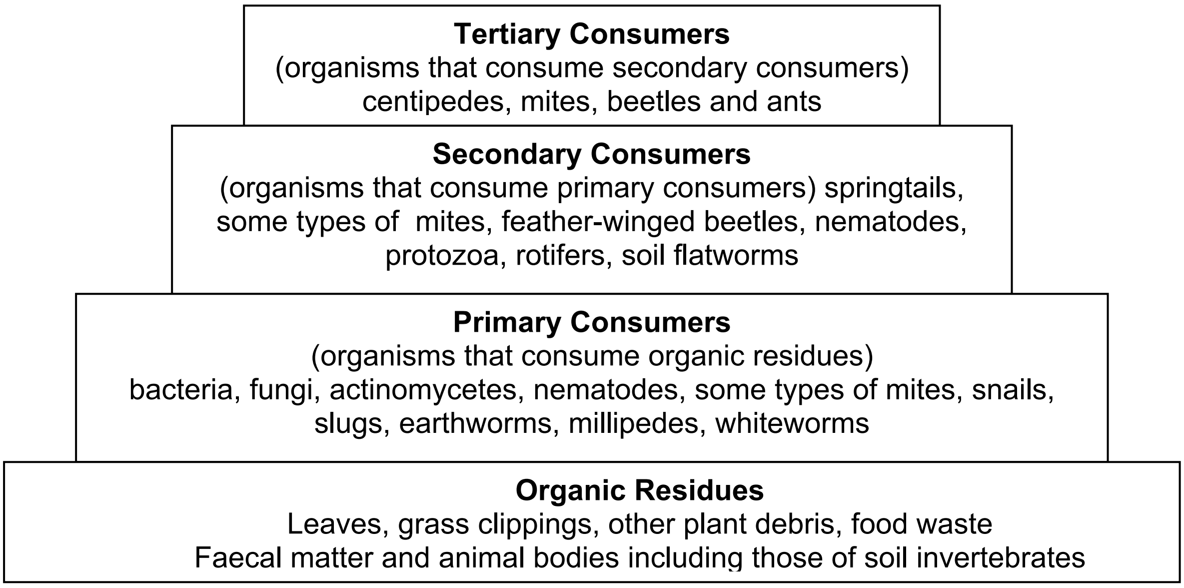

Figure 2.6 Ecological pyramid of organism inter-dependency during composting of solid waste (adapted from Cornell University, 2002)

There is an identified ecological succession of microbial stages and biodiversity operating within conventional, centralised batch operated composting systems. The ecological dynamics shown in Figure 2.6 do not operate in large-scale batch operated systems until the maturation phase as high temperatures occurring during the early thermophilic stages are unfavourable to these organisms. In industrial-scale composting, thermophilic fungi are chiefly responsible for waste degradation. Earthworms and larger invertebrates do not colonise organic matter in centralised composting until the material has cooled and is well matured. However, organisms from all levels of the ecological pyramid coexist in cooler, small-scale HC units and play an important role in waste biostabilisation in these composting systems.

2.4.5 Types of composting system

Conventionally, centralised composting systems vary greatly in the degree of complexity and process control. However, a general distinction can be made between 'open' and 'closed' systems.

In closed systems, the composting material is aerated by agitation, performed by scrapers, augers or a tumbling motion, or by a forced-air blowing system. Open systems may be divided into two basic categories: turned windrows and static piles. In windrow composting the material is formed into elongated piles of triangular cross-section, which are periodically turned to provide aeration and promote drying. In static pile composting, the composting material is not turned or agitated, but remains undisturbed during the 'active' composting period. Aeration is provided by means of fans, which blow or suck air through the compost stack via a system of perforated pipes located beneath the pile. The compost remains on the aeration manifold for the period of maximum decomposition, when most air is required. When active process control by aeration is no longer necessary the material is removed for maturation.

Aeration is normally applied according to one of the two basic strategies. In the 'Beltsville' process, aeration is provided at rate sufficient to maintain the residual O_2 concentration in the pile between 5 and 15 %. The 'Rutgers' aeration strategy is based on a temperature feedback system, which holds the temperature of the composting pile to below 60ºC (Finstein *et al.*, 1985b). The Beltsville and Rutgers strategies are compared in Table 2.14.

In contrast, HC is performed using a small proprietary compost bin, usually constructed from plastic material (typical volume = 0.2 – 0.3 m^3), or a heap, which may or may not be contained within a constructed retaining structure of wood, masonry or other suitable material. Small amounts of waste material are regularly added to form stratified layers over a long period of time and composted material is removed from the bin on an infrequent basis (eg once per y). As a consequence of the small size, metabolically generated heat is not retained as efficiently as in large piles of composting solid waste, as is the case in centralised composting. Therefore, temperatures achieved in small-scale composting units may be generally cooler than the thermophilic conditions required for rapid composting or organic waste in centralised systems. Composting in small-scale systems generally proceeds at mesophilic temperatures, or cooler (Suler and Finstein, 1977; McKinley et al., 1986). In contrast to the control strategies indicated in Table 2.14 for large-scale processes, small-scale systems require little management intervention to biostabilise waste.

Table 2.14 Comparison of Rutgers and Beltsville composting process control strategies (Finstein *et al.*, 1985b)

Parameters	Rutgers	Beltsville
Process control operational objective	Maintain 60ºC temperature ceiling	Maintain O_2 at 5 % to 15 %
Fan control	Fixed schedule initially, followed by meeting temperature feedback	Fixed schedule throughout
Fan size	Must peak demand for heat removal	Prescribed as 1/3hp per 50 ton pile
Fan operation mode	Forced-pressure i.e blowing	Vacuum induced i.e sucking
Consequence of strategy	System oxygenated; a high rate of heat generation and vaporization; dryness may come to inhibit activity, unless prevented; good pathogen kill	System oxygenated; temp peaks, by default, at an inhibitively high level (80ºC); a low rate of heat generation and vaporization; good pathogen kill

2.4.6 Environmental factors

The changes in microbial population and their activities characterise the various stages of the composting process, and are related to changes in environmental variables (Schulze, 1961; Suler and Finstein, 1977; Rao *et al*., 1996). These variables include temperature, moisture content, oxygen availability, pH, nutrient balance and substrate.

2.4.7.1 Temperature

It is widely accepted that temperature is an important environmental variable in composting efficiency (Namkoong and Hwang, 1997; Joshua *et al*., 1998). Not only is microbial metabolism highly temperature dependent, but also the population dynamics (e.g. composition and density) of microbes are dramatically influenced by temperature. In general, each group of organisms has an optimum temperature range, and significant deviations from the optima are manifested by a decline in growth and activity of the organism.

Temperature increase within composting materials is a function of initial temperature, metabolic heat evolution and heat conservation (Miller, 1992a). The achievement of a minimum temperature is essential to an effective composting process (Finstein and Morris, 1975; Finstein *et al*., 1986) and contributes substantially to the high rates of decomposition required during processing of organic waste in large-scale composting systems (Miller, 1992a). Indeed, temperatures below 20 ºC significantly slow or even stop the composting process (Mosher and Anderson, 1977). Temperatures in excess of 60 ºC also reduce microbial activity as the thermophilic optimum of microorganisms is surpassed (Miller, 1992a). The microbial community becomes severely impeded at 82 ºC (Nell and Wiechers, 1978; Fermor *et al*., 1979; Finstein *et al*., 1986). As a consequence, biological activity declines and the temperature falls, and providing moisture, O_2 and substrate are not limiting, activity and temperature will increase again after a lag phase as the composting mass is recolonised. Optimum control temperatures in large-scale centralised composting systems are designed to maximise decomposition and are in the range of 52-60 ºC (MacGregor *et al*., 1981; Bach *et al*., 1984; McKinley and Vestal, 1984). Under these conditions, organic wastes can be rapidly stabilised within 2-3 weeks, although a maturation stage of 2-3 months is also necessary to complete the waste treatment process. In HC systems, however, biological activity is slower and occurs in the psychrophilic and mesophilic temperature ranges and stabilisation is achieved over a longer period of time compared to large-scale, centralised treatment processes (Suler and Finstein, 1977; McKinley *et al*., 1986).

In large-scale centralised systems, practical temperature control is achieved by heat removal based on evaporative cooling and forced pressure ventilation (De Bertoldi *et al*., 1982; Kuter *et al*., 1985; Finstein *et al*., 1986). However, such control is unnecessary in small-scale systems as maximum temperatures are not limiting to composting activity.

Thermophilic temperatures are critical for the destruction of pathogens, parasites and weed seeds in large-scale centralised systems. Hygienisation is usually considered to have been achieved when all of the compost has been exposed to temperatures above 55ºC for a minimum of 4 h (Hoitink, 1993). However, the temperature conditions achieved in home composters are unlikely to reliably destroy pathogens or viable weed seeds. The relatively long residence times for waste in home composters allows the natural decay of pathogens to occur. Nevertheless, depositing animal faeces and weed seeds into home compost bins should be avoided because their elimination cannot be guaranteed (also there are restrictions on the types of food waste that can be deposited under the animal byproduct regulations – see section 2.1.6.5)

2.4.7.2 Oxygen
Oxygen (O_2) is essential for the metabolism and respiration of aerobic microorganisms, and for the oxidization of organic matter. Oxygen uptake is related to heat evolution and 14 MJ of heat energy is released per kg O_2 consumed (Finstein *et al*., 1986). The O_2 requirement varies during the different stages of composting and demand is greatest during the initial and thermophilic phases when the microbial population is rapidly increasing and the rate of biochemical activity is high. As biological activity progresses, the O_2 concentration in the interstitial void spaces falls and the CO_2 concentration increases. During mesophilic stabilisation, demand for O_2 is lower and decreases further through the cooling and maturation stages (Devisscher, 1997).

2.4.7.3 pH value
Different groups of microorganisms involved in composting organic waste have varying optimal pH requirements. Although organic substrates with a wide range of pH values (pH 3-11) can be composted (Nell and Ross, 1987), microbial activity and thus the rate of composting is greatest at pH values between 5.5 and 8.0 (DeBertoldi *et al*., 1983). Bacteria thrive in near neutral pH conditions whereas fungi prefer an acidic environment (Zucconi and de Bertoldi, 1986).

In the early stages of the process, the activity of acidogenic bacteria degrades polysaccharides and cellulose to organic acid intermediaries, resulting in an initial decrease in pH to around 5.0. At temperatures above 40 ºC the activity of the mesophiles is reduced and degradation is continued by the thermophilic fungi. The pH subsequently increases and may reach 8.0-9.0 potentially liberating gaseous NH_3 if excess readily available N is present (Goldstein, 1991).

2.4.7.4 Moisture content
Water is essential in the composting process to transport microbiological metabolites and to act as a solvent in which chemical reactions take place (Stentiford, 1996; McCartney and Tingley, 1998). The suitability of a particular moisture content in a composting system is determined by two factors:

(1) the direct needs of the microbial population;
(2) the effect on gaseous O_2 concentrations in the composting mass.

Low moisture contents cause early dehydration during composting that arrest the biological process, thus giving physically stable but biologically unstable composts (de Bertoldi *et al*., 1983). High moisture contents, on the other hand, limit O_2 diffusion into the composting matrix and increase pliability of the materials (Das and Keener, 1997). This can reduce air permeability and increase aeration costs. Excess moisture may also produce anaerobic conditions from water logging preventing aerobic composting activity (Schulze, 1962; Tiquia *et al*., 1996). The optimum moisture content for efficient composting is in the range 50-60 % of the wet weight (Suler and Finstein, 1977; McKinley *et al*., 1986; Tiquia *et al*., 1998). A drop in temperature during the normal exponential rise, or the plateau period, is usually an indication that either the moisture content is too low (i.e. inhibition of microbial activity) or too high (i.e. inadequate aeration), provided that the other factors are suitable (Diaz, 1993).

In small-scale home composting systems, the moisture content of kitchen and garden waste is typically more than 70 % and requires balancing with bulking agent materials of lower moisture status, such as card or paper, to reduce the moisture content and encourage aerobic biodegradation activity.

2.4.7.5 Nutrient balance and substrate supply

Typical characteristics of input waste feedstock materials for composting in large-scale centralised systems are listed in Table 2.15. Of the many elements required for microbial decomposition, C availability and N balance are fundamental to the activities of microorganisms during the composting process. The assimilation of C and N has a role in growth and nutritional uptake. Nutrients required in small amounts (micronutrients) include: P, Ca, Na, Mg, S, Fe and trace elements such as Zn and Co (Biddlestone *et al*., 1987).

Carbon supplied by the feedstock substrate provides the main source of energy for respiration and cell synthesis, and N is essential in proteins, nucleic acids and enzymes required for microbial growth. Consequently, much more C than N is required and the optimum C:N ratio of the feedstock to meet the cellular demands for these elements is 20:1 to 25:1 (Diaz, 1993). The effects of C mineralization and release of respired CO_2 by the microbial biomass are seen through a reduction in the C:N ratio typically from an initial value of 30:1 to 10-15:1 for the maturated product since two-thirds of the C utilised by microorganisms is given off as CO_2. The remaining third is incorporated along with N into microbial cells and is later released as these cells die and are themselves mineralised (Richard and Trautmann, 2002). A wide range of organic materials are suitable for composting and the C:N properties for some of these are listed in Table 2.16. Materials used predominantly in HC systems such as grass clippings and vegetable wastes contain large amounts of N and moisture suggesting that inputs of dry, high C materials, such as waste paper and card, would benefit the composting process by balancing the C:N ratio and moisture status.

Nutrient availability is a critical factor influencing the rate and time course of the composting process. Most of the N found in a composting mixture is organic, principally as part of the structure of proteins and simple peptides. The first stage of the organic N degradation process involves the mineralization of N to NH_4^+ by ammonification reactions. Ammonium-N is released if N is present in the organic matter in excess of cellular requirements when the C:N ratio of the feedstock is <20:1 (de Bertoldi *et al*., 1983; Newton, 1983). Higher C:N ratios cause slower degradation rates as mineralization processes becomes limited by the availability of N, in which case mineral N is not released until a proportion of the organic C is metabolised and released as CO_2.

Consequently, microorganisms pass through more growth cycles under N limitation requiring a longer period to break down the available C substrate.

Table 2.15 Optimum characteristics for final composting mixture (adapted from TCA, 2001)

Parameter	Optimum range	Reason	Action
C:N ratio	25:1-40:1	Provides necessary proportions of carbon and nitrogen for cell formation in composting microorganisms	Adjust by adding material with complementary C:N ratio
Moisture content	40 % - 60 %	Vital for microbial activity and acts as a medium for biochemical reactions	Adjust by adding material of complementary moisture content or by adding water.
Bulk density	500 to 750 kg m^{-3} with 650 kg m^{-3} as optimum	A high bulk density implies that there is little free air space available between particles. Feedstock with low densities <500 kg/m^3 may have difficulties in retaining heat if open windrows are used. When bulk density is >750 kg/m^3, anaerobic conditions will occur rapidly.	Add material with higher VOCs content.
Volatile solids content	At least 40 % of dry mass	Allows for rapid heating.	Add material with higher VOCs content.
pH	6-8	pH around neutral (7) provides optimum conditions for microbial growth	Difficult to change
Structure	Particle diameter of 25-50 mm	Larger particle size exposes less surface area for microorganisms to attack. Smaller particle size may limit airflow.	Mix of material at the start is the key element, especially with windrow composting. If particle size too large, shred. If too small, add material with larger particle size.

Ammonium ions may be transformed into NO_3^- by nitrifying bacteria when the temperature of the mixture is below 40 ºC and when aeration conditions are favourable. Under anoxic conditions, where the supply of O_2 is inadequate, NO_3^- is utilised as an alternative electron acceptor to support metabolism and undergo denitrification (Tisdale *et al*., 1985). During nitrification, the pH of the medium may be lowered due to the liberation of H^+ ions and the overall process of microbial N oxidation can be summarised in the following equations:

Nitrosomonas bacteria: $2NH_4^+ + 3O_2 \rightarrow 2NO_2^- + 4H^+ + 2H_2O$

Nitrobacter bacteria: $2NO_2^- + O_2 \rightarrow 2NO_3^-$

2.4.7 Compost maturation

Compost maturation is critical to its agronomic use. There are many criteria to judge the maturity or completion of a composting process. Physical characteristics such as colour, odour and temperature give a general indication of the decomposition stage reached, but provide little information regarding the degree of maturation. However, homeowners producing compost from waste will need to rely on such visual assessment of the physical attributes of the composted residue to determine whether it is suitable for use.

Some of the approaches to measure the degree of compost stabilization in large-scale commercial composting include:

1) Temperature decline at the end of composting (Haug 1980b);
2) Decrease in organic content of the compost as measured by the volatile solid (VS) content, chemical oxygen demand (COD), percentage C or ash content, and C:N ratio (Hue and Liu, 1995);
3) Extent of nitrification: reduction in NH_4^+ concentration and increase in NO_3^- (Finstein and Miller, 1985)
4) Rise in cation exchange capacity (*CEC*) during the humification process (Harada and Inoko, 1980);
5) Biological methods involving seed germination and root length (Zucconi *et al*., 1981), since immature composts may contain phytotoxic substances such as phenolic acids and volatile fatty acids (Kirchmann and Widen, 1994);
6) Respirometric techniques and biodegradation kinetics (Lasardi and Stentiford, 2000);
7) Microbial biomass count, its metabolic activity and the concentration of easily biodegradable constituents;
8) Lack of attraction of insects or development of insect larvae in the final product;
9) Absence of malodour;
10) Presence of white or grey colour due to the growth of actinomycetes (Strom, 1995).

Table 2.16 Typical properties of commonly used feedstocks (adapted from TCA, 2001)

Material	Type of value	% N (dry mass)	C:N ratio	Moisture % (wet mass)	Bulk density (kg m^{-3})
Apple processing sludge	Typical	2.8	7	59	837
Broiler litter	Average	2.7	14	37	513
Corrugated cardboard	Typical	0.1	563	8	154
Cull potatoes	Typical	-	18	78	914
Grass clippings	Average	3.4	17	82	178-475
Horse manure	Average	1.6	30	72	818
Horse manure (race track)	Average	1.2	41	63	-
Leaves	Average	0.9	54	38	59-297
Lumbermill waste	Typical	0.13	170	-	-
MSW	Typical	1.9-2.9	14-16	69	-
Newsprint	Typical	0.06-0.14	398-852	3-8	116-144
Paper mill sludge	Typical	0.56	54	81	-
Sawdust	Average	0.24	442	39	243
Shrub trimmings	Typical	1.0	53	15	255
Straw	Average	0.7	80	12	135
Tree trimmings	Typical	3.1	16	70	769
Vegetable produce	Typical	2.7	19	87	939
Vegetable wastes	Typical	2.5-4	11-13	-	-

Immature compost can introduce phytotoxic materials to the soils, such NH_3 or volatile fatty acids (Iglesias-Jimenez and Perez-Garcia, 1992). Iglesias-Jimenez and Perez-Garcia (1992) therefore proposed that guidelines to determine the maturity of compost should include:

(1) stabilization of the temperature curve;
(2) a water soluble C:N ratio lower than 6;
(3) a ratio of *CEC* to total organic C higher than 1.9;
(4) a ratio of humic acids to fulvic acids higher than 1.9.

2.4.8 Summary

Aerobic stabilisation of biodegradable waste involves the interaction of biological, chemical, and physical processes in all composting systems. The effectiveness of a composting process is dependent upon the groups of organisms that inhabit and stabilize the organic wastes as well as the physical and chemical environment provided by the waste mixture. Degradation processes in HC systems follow a complex ecological succession of colonisation by different physiological groups of psychrophilic and mesophilic microorganisms and also by higher invertebrate organisms. However, in contrast to batch-operated, centralised composting processes, which follow a sequence of colonisation with time, small-scale composting systems receive frequent inputs of waste and contain material at different stages of stabilisation and biodegradation at the same time so that all stages of the ecological hierarchy are coexistent within the bin.

2.5 COMPOST UTILISATION

2.5.1 Introduction

After maturation, composted products are suitable for application to land as a soil improver. Compost maturation is critical to its agronomic use. Potential markets for commercially produced compost include landscaping, land restoration, agriculture, silviculture, biomass crops, bio-remediation, and horticulture (DETR, 1998a). However, uncertainties about the markets for compost and how to market composted products to consumers have been identified as major barriers to the development of centralised composting facilities (TCA, 1999a). Competition from other types of bulky organic residual product is also an important factor and spent mushroom compost is a significant commercial competitor product in the soil conditioner market, although its availability may be localised to areas of mushroom production (DETR, 1998a). The limited extent of source segregation of mixed organic waste in the UK impairs composting of household waste and centralised mechanical separation of unsorted refuse for composting is technologically complex and expensive. Home-composted residues will be utilised in domestic gardens and will therefore also compete to some extent with centrally produced composted materials for the home use market.

2.5.2 Peat substitution

Total horticultural peat consumption in the UK is estimated at 3.4 M m^3 per y, the majority (96 %) of which is used in growing media formulation (DETR/WO, 1999d). Peat is a finite resource and there is increasing concern over the environmental damage caused by large-scale peat extraction (DETR, 1999e). However, significant progress has been made in exploiting alternatives to peat for use as soil conditioners and recent statistics (DETR/WO, 1999e) indicate peat substitutes represent 92 % of the horticultural market for soil improvers, equating to approximately 1.7 M m^3 of material annually. The Institute of Horticulture and the Landscape Institute both recommend the use of peat alternatives for soil improving and mulching. The European Commission's 2nd Draft Working Document on the *Biological Treatment of Biowaste* (EC Environment, 2001a) encourages home composting and the use of compost as a substitute for peat, particularly for general soil application. The UK Government also supports the use of non-peat materials and encourages local authorities to promote composting schemes to source-separate compostable waste to exchange peat for compost (DETR, 1998a).

Peat substitution is possible at no increased cost for soil improving and mulching by composting activities. In addition, avoidance of peat has several other benefits in terms of reducing greenhouse gas emissions including:

- Changes in emissions of CH_4 and CO_2 when mature peat bogs are harvested;
- Emissions from transport and harvesting of peat;
- N_2O emissions from peat bogs.

Peat dominates the horticultural container market because it is a well-established, consistent, disease and weed free, effective and relatively inexpensive material. The availability of peat in the UK and users expectations on quality and reliability have meant that there has been insufficient investment in developing compost as an alternative growing medium (DETR, 1998a).

2.5.3 Horticultural applications for home and MSW compost

2.5.3.1 Growing media

Growing media are rooting substrates other than *in situ* soils in which plants are grown. Peat is still the main organic material used for container growing. Composted biosolids (Gouin, 1993) and wood waste (Lumis, 1976) have been used in combination with peat in the container production of ornamental trees, shrubs and perennial plants. Other materials, including spent mushroom compost (Chong *et al*., 1991), paper mill sludge (Chong and Cline, 1994) and source-separated MSW compost (Chong, 1999) have also been tested as potential peat substitutes in container media. Use of MSW compost as a potting media or media amendment is the topic of much research (Gouin, 1993; Lumis, 1976; Chong *et al*., 1991; Chong and Cline, 1994; Chong, 1999). A recent example of this includes a greenhouse pot study evaluating MSW compost-peat mixtures as growing-media, incorporating MSW compost at rates of 0 %, 10 %, 20 %, 30 %, 40 % and 50 % by volume, for potted geranium (*Pelargonium x hortorum* Bailey cv. Meridonna) production (Ribeiro, 1999). This showed the optimum peat blend contained 15-20 % provided that adequate amounts of supplementary N and P were also supplied. In general, however, salinity (Siminis and Manios, 1990), concentrations of phytotoxic ions (Gouge and Sanderson, 1975), low total porosity (Raviv, 1998) and the variability in MSW compost properties (Vavrina, 1995) limit the use of MSW compost as a peat replacement for container plant production.

2.5.3.2 Soil conditioning

Bulky organic materials are added to soil to improve the physical condition of the soil environment (DETR, 1999d). Composts are beneficial as soil amendments principally because of their organic matter content and home produced composts are suitable primarily for general soil conditioning purposes. Field studies have shown that composted MSW residues are an effective soil conditioner and improve soil physical properties by lowering bulk density and increasing water holding capacity, and also by supplying essential nutrients to a limited extent (McConnell *et al*., 1993; Rosen *et al*., 1993; Raviv, 1998). Compost can also be used in top soil manufacture by mixing with soil and sand for use as a landscaping material (HDRA, 2000).

2.5.3.3 Mulching and top dressing

The main purposes of mulches are to suppress weeds and to conserve soil moisture. Composts used for application to the soil surface can be coarsely graded and are spread to a thickness of at least 25 mm (DETR, 1998a; HDRA, 2000). The thermophilic temperatures achieved during industrial scale composting operations kill weed seeds and plant pathogens (Shiralipour and McConnell, 1991; Hoitnik *et al*., 1976). Compost can also be supplied as a top dressing to lawns at a depth of 5 – 10 mm (HDRA, 2000). Variations in texture, particle size and mineral composition are of less importance when the material is used as a top dressing or a mulch and this application will also therefore suit the characteristics of home produced compost.

2.5.4 Properties of compost

2.5.4.1 Physical Benefits

When added to the soil, the organic matter in compost is decomposed further by microorganisms. The resulting humus binds soil particles maintaining soil structure and soil porosity for aeration and drainage. The pore spaces between particles carry out different roles according to their size. Large pore spaces allow aeration, water to drain quickly or can be filled by an extending plant root. Small pore spaces act as nutrient and water reservoirs and are vital for keeping sub-surface layers of the soil moist and for supplying adequate water to plant roots, assisting root penetration. Compost also improves the structure of the soil by making it more workable and more resistant to compaction. This provides a better environment for supporting plant growth and reduces soil erosion (TCA, 2001).

2.5.4.2 Chemical Benefits

The chemical benefits of compost application to soil are identified as:

- Increase pH of acid soils (Wershaw, 1993 and Giusquiani *et al*., 1988). The buffering capacity of soil to pH fluctuation is increased by raising the soil organic matter content (Shiraipour, 1992 and Allievi, 1993);
- Slow release of major plant nutrients (N, P, K); secondary nutrients (Ca, S, Mg) and trace elements for plant growth (TCA, 2001).

2.5.4.3 Biological Benefits

Composting represents a complex range of interdependent biological processes carried out by microorganisms and higher animals to accomplish waste stabilization. Organic matter addition to soil increases populations of beneficial soil animals, such as earthworms, which are important for mixing and for aerating soil (HDRA, 2000). Earthworms have a key role in the decomposition of organic matter in small-scale composting systems and are among the larger compost organisms. Earthworms (*Dendrobena* sp and *Eisenia* sp) eat decaying vegetation and microbes and excrete organic compounds that enrich compost. Their tunnelling facilitates compost aeration and their feeding increases the surface area of organic matter for microbes to act upon. Fresh casts are markedly higher in bacteria, organic material, and available N, Ca, Mg, P and K than soil itself. As each decomposer dies or excretes, substrate resources are made available to the ecological web to support other decomposing organisms (Elcock, 1995).

Composted wastes are recognised as having the potential to suppress plant infections from certain types of soil borne disease, reducing the need for chemical pesticide inputs and control measures. For instance, green waste compost has demonstrated potentially useful effects on disease control at a commercial scale (Barkdoll *et al*., 1992).

Pathogenic microorganisms that cause plant disease are controlled by other microorganisms, which are either added to the soil in compost or are indigenous to the soil and are stimulated by compost application. The mechanisms involved in plant disease suppression are not fully understood, but are thought to be related to competition for substrate resources, parasitisation of the pathogens and/or release of antagonistic, toxic agents. There is a view that the use of composts may significantly reduce the cost of disease control in crops and facilitate the production of crops to organic standards (i.e. without synthetic pesticides) (TCA, 2001).

2.5.5 Summary

Composted products have significantly improved physical and handling characteristics compared with untreated wastes. The physico-chemical properties of home produced compost and composted MSW make them suitable for use as soil ameliorants and, in specialized outlets such as amenity horticulture and landscaping, they are effective alternatives to peat for general soil conditioning. The organic matter content of soil is one of the main factors that determines its intinsic fertility (HDRA, 2000) and the main advantages of compost addition arise from improving the structural properties of soil and soil biological activity (HDRA, 2000; TCA, 2001).

2.6 COMPOST QUALITY

2.6.1 Introduction

The quantities and range of waste types treated by composting, and their application to land, is likely to expand in the future in response to the controls on landfilling biodegradable waste. Composting can significantly improve the physical, chemical and microbiological properties of wastes enhancing their suitability for use on land. However, because some potentially hazardous or visually contaminating components of the waste feedstocks used in composting may be transferred to the end-product (eg physical contraries such as glass and plastic, heavy metals and pathogenic microorganisms), quality assurance standards are necessary to avoid environmental problems. These are also important to develop consumer/user confidence in the safety and uniformity of waste derived, composted products for soil improvement.

2.6.2 Standards

2.6.2.1 Standardisation of composting processes and end-products

Compost quality is recognised as an important factor in the success of composting schemes. Recognised standards are essential to raise users' awareness of, and promote confidence in, the performance and safety of compost, to encourage and to ensure a safe and sustainable use of the product. Standards cover both the process (for example feedstock, suitable conditions for decomposition and sanitisation during composting and quality control) and the product itself, and a mechanism of inspection or self-monitoring to provide assurance that the criteria have been met (DETR, 1998a).

It is desirable to have a reference standard against which to judge whether compost is of an acceptable quality for a particular use and to assess its impact when released into the environment. Compost can be used for a range of applications, for example as a growing medium, soil conditioner or mulch, and in a variety of circumstances, including landscaping, horticulture, land restoration and agriculture. Consequently, different standards of product and production are appropriate depending on the end use requirements (Table 2.17). Such standards enable potential users to choose a compost which is suitable for the intended purpose and to ensure that producers can supply the compost at the quality that it is required (DETR, 1998a).

Table 2.17 Safety information on the main categories of end use (adapted from Nichols, 2000)

Parameters	M	SI	TM	GM	T
Levels of PTEs (Cd, Cr, Cu, Pb, Hg, Ni and Zn)	+	+	+	+	+
Organic matter content as measured by loss on ignition (LOI)	+	+	+	+	+
Carbon to nitrogen ratio (C:N)	+	+	+	+	+
Bulk density	+	+	+	+	+
Moisture/dry matter content (expressed as a range)	+	+	+	+	+
Major feedstock constituents (over 10 %)	+	+	+	+	+
Electrical conductivity	_	+	+	+	+
Soluble/plant available nutrients (nitrate, ammonium, phosphate, potassium) and chloride	_	+	+	+	+
Maturity (test carried out to be declared with results)	_	+	+	+	+
Plant tolerance	_	+	+	+	+
Particle size analysis	_	_	+	+	+
Air-filled porosity	_	_	_	+	+
Water holding capacity	_	_	_	+	+

Key: M=mulches, SI=soil improvers; TM=topsoil manufacture; GM=growing media; T=turf products

The recommended parameters for attachment to primary packaging or supplied on an accompanying information sheet for commercial composts include (Nichols, 2000):

- Designation of compost (compost-derived soil improver, growing media constituent, mulch etc);
- ‘Best before’ date;
- Batch identification code where this is not the ‘best before’ date;
- Name of producer or for whom produced, with contact details;
- Storage instructions;
- Declaration of how to use;
- Basic safety advice;
- Health and safety warning with appropriate safety symbols.

2.6.2.2 Europe

The 2nd draft of the Working Document on the Biological Treatment of Biowaste (EC, 2001a) indicates the type of quality criteria for waste-derived compost that may be required in future European legislation. In relation to quality, producers could be required to ensure that compost contamination is minimised as far as possible to protect soils, crops, animals and man following the precautionary principle. The Working Document proposes quality criteria for two classes of compost (Table 2.18) and these would apply to the compost immediately after the composting phase and prior to mixing with other materials. The proposals described in the Working Document may be indicative of future EU legislation that would supersede other European standards for compost quality. However, it is important to highlight that, in Annex I of the document (EC, 2001a), different feedstocks of compostable wastes used for home composting including: vegetable and fruits (0203), paper (0303) and garden (2020) wastes have no restrictions or cautionary guidance.

A number of Member States in the EU have established national or industrial standards for composts, including independent monitoring and certification schemes. The EU Eco-label for Soil Improvers (which includes, but is not restricted to compost) was also set up in 1993 to assist the public to identify products that have reduced environmental impact over their entire life cycle (DETR, 1999d). This represents the only operational pan-European standard that has a bearing on compost quality although its adoption is not obligatory.

The European Committee for Standardization (CEN) CEN/TC/223 is preparing standards for soil improvers and growing media to facilitate trade in these products within the EU and, again, this is not mandatory unless individual countries specify them within statutes. A Technical Committee (CEN/TC 223) was set up in 1990 to work on the development of pan-European standards to safeguard and develop markets for these products by ensuring that growing media and soil improvers are fit for purpose. CEN/TC/223 has four Working Groups:

- WG1: labelling;
- WG2: safety-to the environment, to crops and to users;
- WG3: sampling and estimate of quantity;
- WG4: methods of test – chemical, physical and biological.

Table 2.18 Proposed EU limit values for compost (adapted from EC, 2001)

Parameter	Compost/digestate(1)		Stabilised biowaste(1)
	Class 1	Class 2	
Cd (mg kg^{-1} DS)	0.7	1.5	5
Cr (mg kg^{-1} DS)	100	150	600
Cu (mg kg^{-1} DS)	100	150	600
Hg (mg kg^{-1} DS)	0.5	1	5
Ni (mg kg^{-1} DS)	50	75	150
Pb (mg kg^{-1} DS)	100	150	500
Zn (mg kg^{-1} DS)	200	400	1500
PCBs (mg kg^{-1} DS)(2)	-	-	0.4
PAHs (mg kg^{-1} DS)(2)	-	-	3
Impurities > 2mm (% DS)	< 0.5	< 0.5	< 3
Gravel and stones > 5 mm (% DS)	< 5	< 5	-

(1)Normalised to an organic matter content of 30 %
(2)Threshold values for organic pollutants would be consistent with the revised Sewage Sludge Directive.

The problems encountered by the CEN working groups charged with constructing these standards have been considerable. For a standard to be adopted, it must meet with the approval of all members. However, the standards adopted previously by certain European countries do not necessarily agree with those recommended by CEN/TC 223 and it has been difficult to gain consensus over many of the issues involved. The work of WG1 (labelling) and WG2 (safety) has published as reports rather than as harmonised standards. However, compliance with a report does not have the same legal status or relevance as compliance with a standard. Also, there are criticisms regarding the appropriateness of the standards themselves because they are not specific to compost, they are pan-European, and they only address the product, not the process (DETR, 1998a; TCA, 2000).

Recently, the EC has outlined the first steps in a strategy specifically focussed on protecting soil (CEC, 2002). As an integral part of the development of the soil strategy the Commission established an Advisory Forum and five Working Groups specialising in the following areas:

- Erosion;
- Organic matter
- Contamination;
- Monitoring;
- Research.

The terms of reference of the Working Group on Organic Matter included consideration of the implications of applying what is described as exogenous sources of organic matter to soil, including by products from agro-industries and consumption of agricultural products, which is relevant to the production and application of composted materials (Robert and Nortcliff, 2004). The Working Group recommended that, for safe application of exogenous organic materials, strict quality control is critical and the long-term sustainable application of these wastes will only be possible through the implementation of measures that reduce pollutant levels in these organic materials. With respect to MSW compost, it is suggested that this will require in general the strict source separation of materials and that separate collection of the biodegradable fraction of household waste would be favoured to achieve the quality objectives.

2.6.2.3 UK

The UK currently does not have a statutory framework for controlling the treatment or quality of composted wastes for land application (Hogg *et al*., 2002). As the UK national standard body, the British Standards Institution (BSI) is obliged to introduce any standards agreed by the European Standards Committee (Comite Europeen Normalisation-CEN). The BSI definition of a standard is a “document, established by consensus and approved by a recognised body, that provides, for common and repeated use, rules, guidelines or characteristics for activities or their results, aimed at the achievement of the optimum degree or order in a given context”. Once European Standards are in place, responsibility for implementation and regulation falls to the BSI or the Environment Agency to ensure that the standards are effective (DETR, 1998a).

The Soil Association (SA) is the most widely known organisation among the systems and products for organic crop production and composting and is recognised by the United Kingdom Register of Organic Food Standards (UKROFS). It offers a Certified Product Scheme linked to the standards and participating composters have their production sites inspected annually to check that products for certification are derived only from permitted or restricted raw materials under specific parameters.

The Composting Association Standards for Composts (TCA, 2000b), launched in May 2000, provided a voluntary scheme for the certification of compost quality and the process by which it is produced. The standards specify product quality criteria including upper limits for heavy metals, inert contaminants and pathogens and are compared to other European standards in Table 2.19. The Association, in conjunction with the Waste and Resources Action Programme (WRAP) are aiming to gain BSI accreditation status of these voluntary standards (TCA, 2000b) and the first step in this process was the production of a BSI Publicly Available Specification (PAS 100) (WRAP, 2002; BSI, 2002). The development of standards appropriate to different end-uses is also under consideration to permit the marketing of lower grade materials for restricted use.

2.6.2.4 Home compost and quality standards

It is important to note that the standards set by TCA do not extend to end products of home composting for self-use and it is recognised that, in most circumstances, the regulation of HC activities is unnecessary and an impractical proposition. Nevertheless, information and understanding regarding compost quality is required to promote safe and effective composting of waste by homeowners (Nichols, 2000).

2.6.3 Health and safety in relation to home composting

2.6.3.1 Risk identification

Although home composting is performed within the vicinity of a domestic garden, there are a number of environmental and health issues that can be identified relating to this practice. These may be linked to the location of the compost bin and end-use including, for example, the production of ready-to-eat crops that may come in direct contact with the compost or amended soil. These hazards can be broadly categorised into physical, chemical (including potentially toxic elements (PTEs) and organic contaminants) and biological. Compared to centralised production of compost from mixed refuse or collected source segregated waste, which may have some residual contamination, home compost is likely to represent the highest potential quality of end product derived from biodegradable household waste. This is because it is produced from segregated garden and kitchen waste and homeowners have a direct incentive to avoid contaminating the compost with undesirable materials that would be applied to their garden soil.

2.6.3.2 Physical contaminants

Physical contaminants potentially present in composted MSW include: stones or fragments of glass, metal or plastics. They represent a potential injury hazard to individuals handling the compost or who come into contact with the compost after application, and may also have a visibly offensive appearance if applied to soil. However, home produce compost should be relatively free of physical contamination due to the segregation of kitchen and garden waste for composting by homeowners. Small amounts of plastic and metal debris may enter the compost attached to paper and card such as transparent films and fasteners, but these are easily identified and removed from the degraded organic material and by sieving the compost before application to the soil.

2.6.3.3 Chemical risk: Potentially toxic elements and organic contaminants

Potentially toxic elements including the heavy metals: Zn, Cu, Pb and Cd naturally occur in the environment, soil, plants and food and are therefore also present in composted kitchen and garden waste. At low concentrations Zn and Cu are essential trace elements for plant growth, but PTEs may be toxic to either plants and/or animals if exposure is high. Organic ligands present in compost may irreversibly bind metallic elements and the bioavailability of heavy metals in compost, for uptake by plants for instance, is limited (De Wit *et al*, 1993). Soil factors also influence PTE bioavailability and decreasing pH value in particular increases plant uptake of the most labile elements including Zn, Ni and Cd, but other important metals such as Pb, Cr, Cu, Hg have comparatively low or very low bioavailabilities and are insensitive to changing soil pH conditions even in acidic soil conditions (Evas, 1989). The PTE content in home produced compost will generally reflect the normal representative background concentrations of these elements in degraded plant material as the biodegradable waste fraction is sorted by the homeowner prior to its input into the home compost bin. Thus, potential sources of PTEs (batteries for instance) will be avoided and, therefore, the PTE content of home produced compost is likely to be smaller than material produced from mechanically sorted MSW (Amlinger *et al.*, 2004). Home produced compost is likely to represent the potentially highest chemical quality of material that can be generated by composting the biodegradable fraction of household waste.

A large range of organic chemicals may potentially contaminate the biodegradable fraction in mixed MSW from the disposal of household hazardous waste. Plant protection chemicals (insecticides, pesticides and herbicides) and organic compounds deposited from the atmosphere onto leaf surfaces (eg PAHs) represent the main groups of organic contaminants present in segregated greenwaste and also in home produced compost. The active aerobic microbial degradation mechanisms operating during composting processes effectively metabolise the majority of organic contaminants potentially present in biodegradable waste and current knowledge indicates that the concentrations of anthropogenic organic chemicals in compost are not of significant concern (Chaney and Ryan, 1993).

In addition to the potential presence of exogenous organic compounds, complex, naturally produced organic substances (endogenous compounds) are generated during the composting process itself. For example, microorganisms produce fatty acids and methylated esters that may be potentially toxic to plant growth, but the rates of addition to soil in maturated compost (<0.025-0.05 mg kg^{-1}) are small and do not represent a risk of phytotoxicity (Gonzales-Vila *et al*, 1982). Leachate produced during large-scale composting activities contains large amounts of soluble organic matter and has a high biological oxygen demand (BOD) requiring containment and treatment to avoid impacting surface water sources. Home composting is unlikely to represent a risk to surface or groundwater contamination from high BOD leachate production due to the small-scale and dispersed locations of biodegradable waste treatment in the systems, although the attenuation of leachates from home compost bins has not been quantified.

2.6.3.4 Pathogens

Pathogens are microorganisms that cause disease through infection. The presence of human pathogens in composting materials is largely dependent upon the feedstock. Under the conditions of thermophilic large-scale centralised composting systems, the temperature generated by the composting process, and the time the compost is exposed to this temperature, is normally sufficient to ensure the effective destruction of pathogens. The nature and quantity of primary pathogens in finished compost will depend on the feedstock and the efficiency of the composting process (Hav, 1996).

Table 2.19 Maximum allowable concentrations of chemical, biological and physical contaminants in composts in various published standards

Contaminant	UK Composting Association Standards for Composts	CEN values for soil improvers*	Soil Improver Eco-label limits (current)
Potentially toxic elements (mg kg^{-1} dm)			
Cd	1.5	1.5	1.0
Cr	100	150	100
Cu	200	200	100
Hg	1.0	1.0	1.0
Ni	50	75	50
Pb	150	150	100
Zn	400	500	300
Other substances toxic to plants			
Phytotoxins	Germination and growth 20 % below control	-	-
Biological contaminants			
	Absent in 25 g	-	Absent in 25 g
	1000 CFU g^{-1}	-	1000 MPN g^{-1}
Weed propagules	5 viable propagules 1^{-1}	-	No product shall introduce unacceptable numbers of weed seeds or the vegetative reproductive parts of aggressive weeds into the soil
Physical contaminants			
Total glass metal and plastic > 2 mm	1 % (m/m) of total air-dried sample (of which < 0.5 % (m/m) of total air-dried sample is plastic)	-	No product shall contain any fragments of glass, wire, other metal or hard plastic which may constitute a hazard to human health
Stones and other consolidated mineral contaminants > 2 mm	5 % (m/m) of total air-dried sample	-	-

Achievement of high temperature is desired not only to speed decomposition rates but also to kill pathogens. The 2[nd] draft of the *Biological Treatment of Biowaste* (EC, 2001a) is the most recent influence proposing operative guidelines for large-scale composting systems (Table 20) to ensure effective sanitisation. In addition, the materials are required to be adequately mixed during the sanitising period, to ensure that all parts of the composting materials are heated to the required temperature. In contrast home compost systems, biological activity predominates at mesophilic temperature ranges over a longer period of time (Suler and Finstein, 1977; McKinley *et al*., 1986) and it is uncertain whether these conditions sufficiently sanitise the compost. Laboratory testing in centralised systems routinely check for the presence of indicator species such as *Salmonella spp*. and *Escherichia coli*. (TCA, 1999).

Table 2.20 Operative guidelines for composting adapted from The *Biological Treatment of Biowaste* (EC DG Environment, 2001)

Compost system	Temperature	Treatment	Turning frequency
Windrow	≥ 55 ºC	2 weeks	5
Windrow	≥ 65 ºC	1 week	2
In-Vessel	≥ 60 ºC	1 week	N/A

2.6.3.5 Bioaerosols

These are microorganisms or other biological particles that are suspended in the air as an aerosol and are generated during the composting process in high concentrations, whenever composting materials are agitated, although they are present naturally at lower levels (Epstein *et al*; 1994; Millner *et al* 1994 and Milner, 1995). Because they are so small and numerous, they can be inhaled and penetrate into the deep parts of the lungs where gas exchange takes place. When present in high concentrations, they can cause illnesses, such as asthma and allergic alveolitis (hypersensitivity, pnuemonitis, granulomatous pneumonitis) and it can cause respiratory infection when the immune system is impaired. The release of bioaerosols from finished compost is at its greatest when the compost is being moved (Mullins *et al*, 1976 and Millner *et al*, 1980).

Of particular interest is *Aspergillus fumigatus* Fres., which is abundant in composting vegetative material (Easywood, 1952; Fergus, 1964; Chang and Hudson, 1967). It is a thermotolerant pathogen and can survive under composting conditions (Cooney, 1964). It is a medically important filamentous fungal opportunist and respiratory allergen, sometimes spreading to other organs or to the central nervous system in immuno-compromised individuals (Hart *et al* 1969 and Emmons, 1970). Records of its high ecological distribution and pathogenicity, suggest that the fungus might pose a health problem for hypersensitive or immuno-sensitive individuals (Haller *et al*., 1974 and Khan *et al*., 1976). In 1994, a U.S. department of Agriculture working group reviewed all the scientific literature published on the release and dispersal of bioaerosols from composting facilities and concluded that Composting facilities do not pose any unique endangerment to the health and welfare of the general public' (Epstein *et al*, 1994; Millner *et al* 1994 and Millner *et al*, 1995). It was one of the first attempts at evaluating health impacts from bioaerosols associated with the processing and handling of biologically degraded materials at composting facilities. Millner *et al* (1994) led a twenty-month expert review of the health impacts of composting facilities and reported the results of a number of other studies. One investigation found *A. fumigatus* concentrations reached 354 CFU m^{-3} and 86 CFU m^{-3} 100 and 500 m respectively downwind of a green waste composting plant. Another study cited by Millner *et al* found that *A. fumigatus* levels reached background concentrations from 75-150 m downwind of a sewage sludge composting plant. As a consequence of these studies, Millner *et al* (1994) concluded that the general public is not generally at risk from systemic infection by *A. fumigatus*.

2.6.4 Summary

Standards provide information on safety and appropriate usage, regulating the composting parameters. Currently, standards determining compost quality are numerous, but are not mandatory and are not extended to home compost products.

Studies determining the importance of contamination from home compost are insufficient. However, potential chemical and biological contaminants may expose different populations to health hazards, ranging from the compost producer to the consumer of vegetable products treated with compost fertilizer, and quantification of these hazards are of paramount importance in light of home composting promotion. In particular, microorganisms which constitute a potential respiratory hazard are more frequent than those which follow the digestive route and are difficult to control. In general, potential hazards associated with large-scale centralised composting systems are of greater magnitude in comparison to small-scale composters due manually pre-sorting of waste materials and elimination of meat and cooked foods, which increase risk of contamination.