Processes and Plant for Waste Composting and other Aerobic Treatment

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This report summarises the findings of a research carried out by the David Border Composting Consultancy. The information within this document is for use by EA staff and others involved in the composting of controlled wastes.

Key Words
Compost, Composting, municipal solid waste, controlled waste, odour, bioaerosols, windrow, aerated static pile, contained composting, environment.

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Executive Summary

Organic wastes and composting

In the EU Member States the latest estimate of the total potential for organic wastes that might be recovered through biological processes is approximately 60 million tonnes.

Currently, about 9 million tonnes (15%) of municipal organic wastes are home composted or separately collected in the EU. About three quarters of all the organic material recovery takes place in three countries: Germany, the Netherlands, and Austria. The main biological technology used to recover this organic waste is composting.

Composting of controlled waste in the UK – the current situation

It has been estimated that in 1998 over 900,000 tonnes of organic waste were composted within the UK.

Two thirds of this organic waste (630,000 tonnes) consisted of the organic fraction of municipal solid waste. If true, this represents an almost threefold increase over the 1997 figures.

58% of the organic fraction of municipal solid waste composted was green waste collected from civic amenity sites, 34% was local authority parks and gardens waste, and 7% was from kerbside collections.

Over 90% of the organic waste composted was processed in 59 centralised composting facilities, 59% of these processed <5,000 tonnes a year and 5% processed >50,000 tonnes a year.

96% of the organic waste was composted in open-air turned windrow systems. Approximately 400,000 tonnes of compost was produced from the total quantity of organic waste composted.

40% of this compost was sold in bulk, 34% was used by composters on site, 17% was sold in bagged form, and the rest was given away or used in blends.

Potential for composting of controlled wastes in the UK

The UK currently landfills 27,000,000 tonnes a year of municipal solid waste and that 60% of this is biodegradable. Under the 1999 EU Landfill Directive the amount of biodegradable municipal solid waste landfilled must be reduced to 75% of the amount produced in 1995 by the year 2010, to 50% by 2013, and to 35% by 2020.

Assuming an annual increase in municipal solid waste production of 3% a year it is estimated that the UK will have to divert from landfill 14,000,000 tonnes of the biodegradable fraction of municipal solid waste in 2010, increasing to 20,900,000 in 2013, and 30,300,000 tonnes by 2020.

Not all of this biodegradable material would be suitable for composting, but it is estimated that 4,900,000 tonnes of biodegradable waste appropriate for composting will have to be diverted by 2010, 7,300,000 tonnes by 2013 and 10,600,000 tonnes by 2020. These figures do not include paper and cardboard.

The composting process
Composting is a complex, aerobic microbiological process capable of converting the organic fraction of municipal solid waste, and many other organic wastes, into beneficial compost products. The composting process can be optimised by controlling the quality of the feedstock and a number of operational parameters.

Composting technologies
There are many different technologies available for the composting of the organic fraction of solid municipal waste. These range from the simple open-air systems (windrow composting and aerated static pile composting) to more sophisticated contained systems.

Currently within the UK, windrow composting is the dominant technology. There are no aerated static pile composting systems and only a few recently established contained systems.

In other European countries, and elsewhere in the world, many different composting technologies are used, especially contained composting systems. A number of these contained composting technologies offer a more efficient composting process, a higher quality compost product, and an improved protection of the environment over the open-air windrow method, but at extra capital and operational cost.

The applicability of contained composting systems within the UK will depend upon relative processing costs.

Waste-derived composts
The quality of waste derived compost depends to a great extent upon the quality of the feedstock used to make it. Compost made from municipal solid wastes will only be of beneficial use, and of commercial value, if it is made to the highest quality possible with sufficient quality control. Depending upon quality, waste-derived composts can be used for land reclamation, and as a soil improver in landscaping, agriculture and horticulture.

Composting to produce Refuse Derived Fuels
In the EU increasing attention is being paid to converting the organic fraction of MSW into refuse derived fuels.

Composting as pre-treatment to landfilling
Various composting technologies are being used in the EU to pre-treat organic wastes before they are landfilled.

Composting – environmental problems
There are a number of environmental problems, or potential problems, that are associated with composting, including odour, leachate, and bioaerosols.

These problems can be reduced or removed by the correct siting of the composting facility, the correct choice of composting technology, and the correct operation of the site.

1. INTRODUCTION

At present, almost all centralised waste composting operations in the UK process organic waste collected from civic amenity sites and separately collected household waste. Almost all of the centralised composting operations use the turned windrow method. However, more advanced composting systems are now being introduced. These new systems differ widely from each other in terms of their method of operation and their [likely] effect upon the environment.

In some other countries, there is much greater experience with these forms of composting technologies. It is the purpose of the report to bring together, and comment upon, information on these systems and related composting matters to assist composters and regulators in the UK in the operation, management, monitoring, and regulation of composting plants.

Information for this report has been collected from many sources in a number of different countries. It includes material published in books, journals, and reports, and stored on the Internet. Information has also been obtained from many commercial companies, associations, government bodies, other organisations and individuals, and from a number of personal visits.

The information obtained from the above sources is incorporated into the main part of the report that examines the background of organic waste composting, especially the composting of biodegradable municipal solid waste, the theory and practice of composting, and the uses of waste-derived compost products. The information is discussed in terms of its relevance to composting in the UK. Reference is made to the sources of the information discussed.

The Appendices contain lists of all of the sources of information discussed in the main part of the report, and lists of further sources, commercial companies, and organisations of relevance. A Glossary of many of the terms used in this report is given at the end.

2. ORGANIC WASTES IN THE EUROPEAN UNION

2.1 Introduction

A number of studies have been undertaken to determine the proportion of organic matter to be found in municipal solid waste in EU (European Union) countries, including Rijpkema et al. 1996, and White et al. 1995. In the EU Member States the latest estimate of the total potential for organic wastes that might be recovered is approximately 60 million tonnes (DHV 1997).

Currently, about 9 million tonnes of the 60 million tonnes of municipal organic wastes are home composted or separately collected (15%) in the EU. About 77% of all the organic material recovery takes place in three countries: Germany, the Netherlands, and Austria.

The two main biological technologies used to recover the above organic wastes are composting and anaerobic digestion. In the EU, composting is the main method of treatment, and only composting is considered in this report. The data are summarised in Table 2:1 (Modified from 'Composting in the European Union')[1]

Table 2:1: Recoverable & composted separately collected organic wastes in EU

EU Member State	Recoverable organic waste (10^3 t/year)	Treated organic waste (10^3 t/year)	Percentage recovery rate (%)	Compost production (10^3 t/year)
Germany	9,000	4,000	45%	2,000
Netherlands	2,000	1,800	90%	650
Austria	2,200	1,100	50%	500
Denmark	900	500	55%	250
Belgium	1,670	320	19%	160
United Kingdom	9,240	317	3%	159
France	14,500	400	3%	150
Italy	9,000	200	2%	100
Sweden	1,500	250	16%	100
Finland	700	70	10%	30
Luxembourg	50	7	14%	3
Greece	1,650	0	0%	0
Ireland	350	0	0%	0
Portugal	1,200	0	0%	0
Spain	6,600	0	0%	0
Total in the EU	**60,560**	**8,964**	**15%**	**4,102**

[1] In descending order of quantity of compost produced.

The DHV study estimated that about 9,000,000 tonnes of organic waste is recoverable each year from municipal solid waste within the UK.

2.2 Collection systems for organic waste in EU

The method by which wastes, including organic wastes, are collected varies considerably from country to country. These are described for all EU countries in the 1997 report by DHV, and in summary form in the Table below:

Table 2:2: Collection systems and treatment methods for organic wastes in EU

Country	Separate collection (for at least some organic waste), home composting, or only integrated collection	Treatment method for separately collected organic waste
Austria	Separate collection and home composting	Composting and anaerobic digestion
Belgium	Separate collection and home composting	Composting and anaerobic digestion
Denmark	Separate collection and home composting	Composting and anaerobic digestion
Finland	Separate collection and home composting	Composting and anaerobic digestion
France	Separate collection	Composting
Germany	Separate collection and home composting	Composting and anaerobic digestion
Greece	Integrated collection	None
Ireland	Integrated collection	None
Italy	Separate collection	Composting
Luxemburg	Separate collection and home composting	Composting
The Netherlands	Separate collection	Composting and anaerobic digestion
Portugal	Integrated collection	None
Spain	Integrated collection	None
Sweden	Separate collection and home composting	Composting
United Kingdon	Separate collection and home composting	Composting

The systems adopted in The Netherlands and Germany are of particular interest to the developing UK composting industry and are summarised below.

2.2.1 Waste collection in The Netherlands

In about 80% of the municipalities the collection is carried out by a municipal department or a commercial company set up by the municipalities (DHV 1997). In most of the remaining 20% of municipalities the waste is collected by one of three large commercial companies. In 1995, 1.45 million tonnes of vegetable, fruit and garden waste was collected. This organic waste is source-separated by the householder. Nearly 100% of householders in the Netherlands participate in this scheme.

2.2.2 Waste collection in Germany

In 1996, vegetable, fruit and garden waste was collected from between 50% and 60% of German households. The target is to collect from 80% - 90% of households. The total quantity of source-separated organic waste collected is between 8 and 10 million tonnes a year (DHV 1997). More than 95% of the vegetable, fruit and garden waste collected was through the use of separate bins at households. The remaining 5% was collected in paper bags or plastic bags. Nearly 100% of the collected waste is composted. Collection is by the use of normal collection vehicles, with collections every two weeks except during the summertime when collections may be every week.

3. ORGANIC WASTES – THE ROLE OF COMPOSTING

3.1 Introduction

Various approaches to the treatment of organic wastes have been examined in a number of recent studies[1]. The role of organic waste composting as an option for organic waste treatment, and the technology of the composting process itself, have been the subject of many studies[2]. A number of studies have been undertaken that compare the performance and applicability of different composting systems, (Jerspersen 1992, Finstein 1993, Lopez-Real and Baptista 1996, Anon 1998a). Many of these studies are examined in later sections of this report.

The environmental effects of large-scale composting, and the associated regulations, have also been the subject of a number of studies [3]. Quantitative comparisons between composting and other methods of organic waste treatment, such as anaerobic digestion, have been undertaken (van Lierop and de Groot 1997).

The composting of many different classes of specific organic wastes has received attention, including those in Table 3.1.

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[1] Pescod 1991, Department of the Environment 1992, Finstein and Hogan 1993, Barbiroli 1994, Curzio *et al.* 1994, Hall and Coombs 1994, Kirchmann 1994, Raggi 1994, EPA 1995, Leikam and Stegmann 1995, Rogalski and Charlton 1995, Sasser 1995, Anon 1996, Anon 1996a, Bardos and Forsythe 1996, Cossu and Muntono 1996, Diaz *et al.* 1996, Hansen 1996, Hummel 1996, IETC 1996, Naylor 1996, Nybrant *et al.* 1996, Rogalski 1996, UNEP 1996, EPA 1997d, White 1996, Barton 1997, Holland 1997a, Koller and Thran 1997, Leikam and Stegmann 1997, Sonesson *et al.* 1997, UNEP 1997a, White 1997, Anon 1998b, Stentiford 1998, Washington State Department of Ecology 1998, McGarrity 2000.

[2] Gray *et al.* 1971, Gray *et al.* 1971a, Gray *et al.* 1971b, Golueke 1972, Finstein and Morris 1975, Poincelot 1975, de Bertoldi *et al.* 1983, Anderson and Smith 1987, Bertoldi *et al.* 1987, Golueke *et al.* 1987, Benedict *et al.* 1988, Anon 1989, EPA 1989a, Anon 1991, Anon 1992a, Cornell Composting 1992, De Jong 1992, Finstein 1992, Funke 1992, Harrison and Richards 1992, Rynk 1992, Cornell Composting 1993, Department of the Environment 1993c, Diaz *et al.* 1993, DoE 1993, Doe 1993a, Diaz *et al.* 1993a, EPA 1993b, EPA 1993c, Haug 1993, Hoitink and Keener 1993, Newport *et al.* 1993, Anon 1994a, EPA 1994, Oorthuys *et al.* 1994, Scharff and Oorthuys 1994a, Poll 1995, De Bertolidi 1995, De Bertolidi *et. al* 1996, EPA 1996, Golueke and Diaz 1996, IETC 1996, Inbar 1996, Lennes 1996, Papadimitriou and Balis 1996, Skinner 1996, Stentiford 1996, UNEP 1996a, UNEP 1996b, Cornell Composting 1997, Epstein 1997, DHV 1997, Richard and Walker 1997, Walker *et al.* 1997, Anon 1997v, Compost Resource Page 1997, Richard 1997, Wiemer and Kern 1997, Day *et al.* 1998, Harrington 2000

[3] Diaz *et al.* 1987, Harper *et al.* 1992, De Bertoldi 1993, De Haan and van der Zee 1993, Ryan and Chaney 1993, Shrimp 1993, Ryan and Chaney 1994, Gronauer *et al.* 1996, Kashmanian and Rynk 1992, Piavaux 1996, Walker 1996, Avnimelech 1997, Environment Canada 1997, EPA 1997, Wheeler 1997a, Anon 1998e

Table 3:1: Composting of specific wastes

Type of waste	References
▪ Domestic and sewage wastes	(Yusuf et al. 1991, Nordstedt et al. 1993, Bloxham and Colclough 1996, de Wilde et al. 1996, Verschut et al. 1996, van der Werf 1998)
▪ Agricultural wastes	(Genevini et al. 1996, Horwath et al. 1996, Lopez-Real 1996, Anon 2000)
▪ Commercial, industrial & hazardous wastes	(Goldstein 1992, Ziggenfuss et al. 1991, Williams and Keehan 1993, Civilini et al. 1996)
▪ Pesticides	(Fogarty and Tuovinen 1991, Michel et al. 1996c, Kuo and Regan 1998)
▪ Food wastes	(Croteau and Alpert 1994, Donahue et al. 1998, Sullivan et al. 1998)
▪ Pallet and other wood wastes	(Cooperband and Stone 1998, Glenn 1998b, Glenn 1998c)
▪ Cardboard and paper	(Raymond 1995, Shin et al. 1996, Farrell 1998)
▪ Poultry manure	(Brodie et al. 1996, Raviv et al. 1999, Bordie et al. 2000)
▪ Fish and crustacean waste	(Cato 1996, Laos et al. 1998, Minkara et al. 1998)
▪ Napthalene	(Civilini and Sebastianutto 1996)
▪ Slaughter house wastes	(Rossi et al. 1996)
▪ Silicon polymers	(Smith et al. 1998)
▪ Vermiculture wastes	(Rynk et al. 1998)
▪ Animal mortalities	(Brodie and Carr 1997, Farrell-Poe 1998)

Large quantities of domestic, sewage and commercial wastes can be diverted to on-farm operations (Anon 1998j, Christian et al. 2000). Animal manures, particularly in the USA, are composted in great quantities (Hansen et al. 1991, Henry and White 1993, Inbar et al. 1993, Mahimairaja et al. 1994, Insam et al. 1995, Anon 1998l, Carr et al. 1998, Elwell et al. 1998, Glenn 1998a, Glenn 1998d, Goldstein 1998a, Tiquia and Tam 1998). This is often against a background of the concentration of animal production, and hence manures, in larger and larger facilities. High moisture manures can also be composted, (Richard 1998).

Much work has also been carried out on the microbiology of the composting process, (Chang and Hudson 1967, Finstein and Morris 1975, McKinley et al. 1985, Strom 1985, Golueke 1992, Brinton and Droffner 1994, Beffa et al. 1996a, Beffa et al. 1996b, Blanc et al. 1996, Insam et al. 1996) and the compostability of many different classes of wastes, (Lemmes 1994, Pettigrew and Johnson 1995, Kain 1996, Mesuere 1996).

The efficiency with which organic waste, from whatever source, can be collected in a form suitable for composting, has a major effect upon the financial viability of the composting option. A number of different methods of waste separation and collection have been tried (Macy 2000). Many of these are site- and waste-specific, and may also be linked to other recycling activities. Attempts have been made recently to quantify the terms and measurements used in measuring these recycling activities, including composting (Pillsbury 1998). The US Environmental Protection Agency (EPA) has issued a guidance manual for those involved in recycling activities, (EPA 1997k). This includes information on the methodology of measuring recycling activities, definitions, case studies, and work sheets to convert information into a standard format.

A number of studies have been carried out on the use of bio-degradable waste bags, and other biodegradable plastic replacements, to avoid contaminating the feedstock with non-biodegradable plastic material, (Bastioli and Innocenti 1996, Hoppenheidt and Trankler 1996, Silvestri et al. 1996, Nakasaki et al. 1997, Streff 1997, Yagi and Irimajiri 1997, Anon 1998f, Croteau 1998, Riggle 1998). The American Society for Testing and Materials (1996) has looked at the measurement of plastic biodegradation within a commercial composting system

3.2 Organic wastes and composting in the UK

A survey (Composting Association 1999) estimated that the following wastes were collected for composting in 1998 throughout the UK (Table 3.2).

The Composting Association survey indicated that of the municipal wastes collected for composting, 58% was collected from civic amenity sites, and 7% collected from the kerbside. The survey further showed that there has been no significant increase in the collection of waste for composting at the kerbside since 1997, whereas the amount of waste collected for composting from civic amenity sites had more than doubled since 1997.

These figures should be interpreted with the knowledge that in England and Wales, only 16% of all municipal wastes is collected from civic amenity sites and 63% is collected at the kerbside.

Table 3:2: Types of waste composted in the UK in 1998

Type of waste	Quantity composted (tonnes)	% of total waste composted
Municipal		
Household garden waste from civic amenity sites	362,596	40
Garden & kitchen waste collected from kerbside	30,954	3
Garden waste collected from kerbside	11,194	1
Other household	7,081	1
Green waste from local authority parks & gardens	216,548	24
Total Municipal	**628,373**	**69**
Non-municipal		
Green waste from landscaping activities	40,311	4
Industrial processes	146,383	16
Other commercial processes	95,753	11
Total non-municipal	**282,447**	**31**
Total composted	**910,820**	**100**

The present situation regarding composting in the UK is considered in more detail in Section 11.

4. THE COMPOSTING PROCESS

4.1 A definition of composting

Composting can be defined as,

"*the breakdown of organic wastes by micro-organisms, in the presence of air, to produce water, carbon dioxide, ammonia, heat, and a more stabilised, pasteurised organic material (compost)*".

Several glossaries of terms relating to composting are available, (Skitt 1992, Composting Council 1994, Vittur 1996). A brief glossary of composting terms used in this report can be found in the Appendices.

4.2 The basics of the composting process

All composting technologies, whether simple or sophisticated, open or contained, share a number of basic characteristics. These are considered in outline below. Elements of these are re-examined in detail in later sections under individual composting technologies.

The chemistry of the basic composting process is summarised in Figure 4.1.

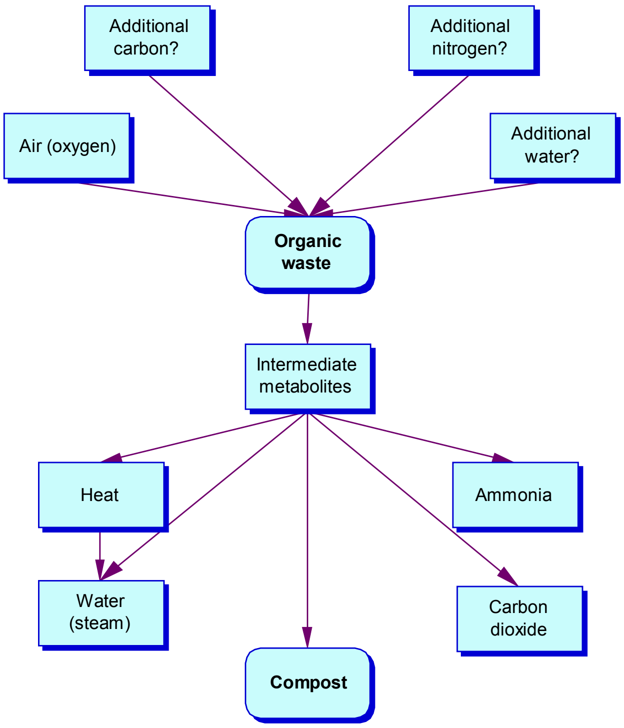

Figure 4-1: The chemistry of composting

Most organic wastes can be represented as a mixture of three groups of chemicals:

- lipids and carbohydrates;
- proteins and amino acids; and
- ash, lignin and cellulose

In composting, a wide range of bacteria, actinomycetes, and fungi act upon these chemicals, in the presence of air (oxygen) and water and produce a number of chemical changes. Some of the lipids and carbohydrates are broken down via intermediates into carbon dioxide and water. At the same time, energy is released in the form of heat. This heat raises the temperature of the composting mass. Some of the proteins and amino acids are also broken down and ammonia may be released. The more resistant components in the organic waste (ash, lignin, and cellulose) contribute to the final compost product, although some of the cellulose is broken down.

The compost product retains about 25% of the carbon in the original feedstock as humic material (Chen and Inbar 1993). It also has low levels of polysaccharide, mainly in the form of microbial cell walls, (Macauley et al. 1993).

In the process of carrying out the above chemical changes, particular micro-organisms (bacteria, actinomycetes and fungi) multiply in the composting waste. Over the period of composting, a series of different types of micro-organisms flourish at different stages. Some of these die and become part of the organic waste being broken down.

The composting process can be viewed as a generalised process diagram, as seen in Figure 4.2. A number of waste materials may be mixed together in order to produce a feedstock with the required physical and chemical properties. This process is discussed in more detail in Section 4.2.

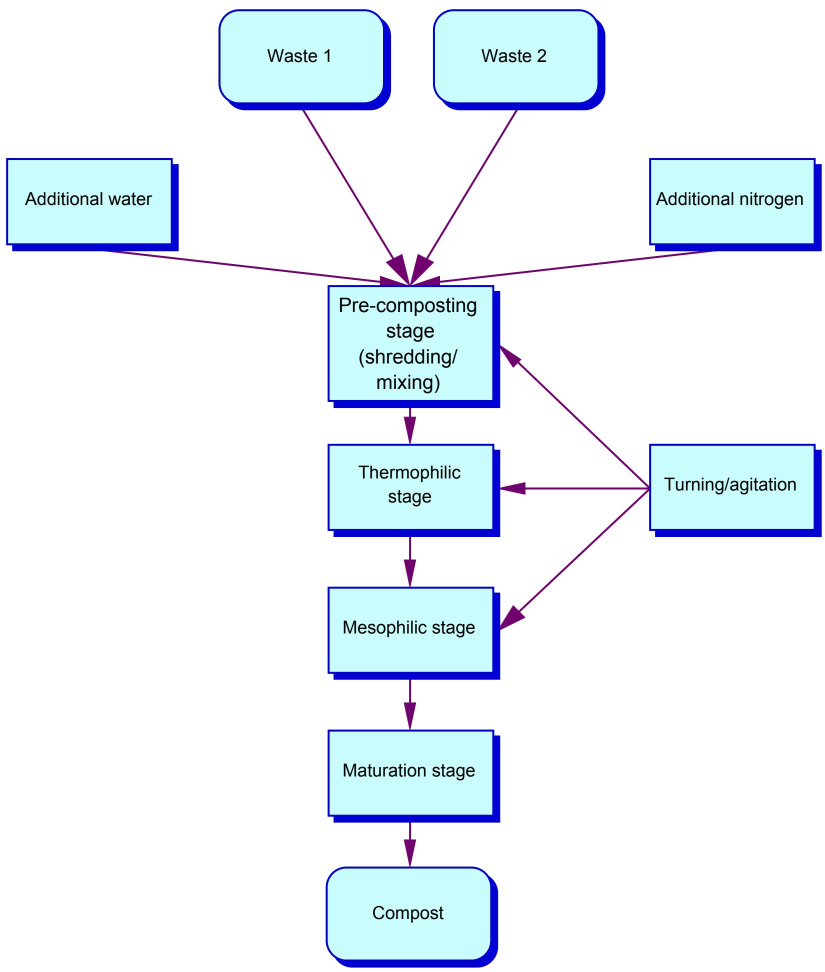

Figure 4-2: A process diagram of the composting process

4.3 The pre-composting stage

The first stage of a composting process is referred to as the pre-composting stage and normally involves shredding the wastes to a small particle size (1 - 2 cm), mixing the wastes together thoroughly to produce a homogeneous feedstock, and adding water, if necessary, to optimise the moisture of the mix (Richard 1992, Tyler 1998). In some composting systems wood chips or shredded rubber tyres are used to improve the physical structure of the composting mass, (EPA 1987a). These materials may not be significantly changed by the composting process and can be re-used a number of times after being screened from the compost during the post-processing stage. The pre-composting stage is normally carried out over a period of a single day.

4.4 The thermophilic composting stage

The next stage of the composting process is variously called the first stage, rapid stage, Phase I or high-temperature stage, during which the temperature of the composting mixture can rise to between 45º C and 75º C. Much of the initial breakdown of the waste occurs at this point. At the end of this stage the material may be screened, to remove oversized particles before continuing composting these can be returned to the start of the process, re-shredded or disposed of. This stage may last between 3 days and a number of weeks, depending upon the type of composting technology employed.

4.5 The mesophilic composting stage

This stage, variously called conditioning, second stage, Phase II or lower temperature stage, takes place at a lower temperature (45-50°C). This temperature may be reached naturally, as the high-temperature stage comes to an end, or it may be brought about by the operator increasing the supply of fresh air to the compost and thereby cooling it. It may from last several days to a number of weeks depending upon the composting technology used and the type of compost being made.

4.6 The maturation stage

This stage is also called the curing stage and takes place at even lower temperatures, between ambient and 45°C. Many further chemical reactions occur during this stage to produce mature and stable compost, for example the conversion of ammonium to nitrate. Depending upon which type of compost is being made, this stage may be missed out. Some applications may be able to use compost directly after the mesophilic (conditioning) stage, while others may require very stable compost that has been allowed to mature for several months.

4.7 The end-point of composting

A number of approaches have been taken to defining the end-point of the composting process and in determining the degree of stability of the compost product (Inbar et al. 1990, Chen and Inbar 1993, Herrmann and Shann 1993, Iannotti et al. 1993, Mathur et al. 1993, Mathur et al. 1993a, Schnitzer et al. 1993, Grebus et al. 1994, Iannotti et al. 1994, Avnimelech et al. 1996, Barberis and Nappi 1996, Berner et al. 1996, Ciavatta et al. 1996, Dinel et al. 1996, Dinel et al. 1996a, Farrel 1996, Kuhner and Sihler 1996, Lasaridi and Stentiford 1996, Massiani and Domeizel 1996, Otero 1996, Sanchez-

Monedero et al. 1996, Seekins 1996, Becker 1997, Gattinger et al. 1997, Jackson and Line 1997, Lasaridi and Stentiford 1997, Tiquia and Tam 1998, Adani et al. 1999).

The end-point of a composting process is ultimately determined by the required specification of the compost product. Some applications of waste-derived composts require a highly stabilised product. This requirement will apply, for example, when the composted material is to be part of a formulation of a growing medium that may be supplied and stored in plastic bags. Other applications, for example as a bulk soil improver in agriculture, will require a much less demanding level of stabilisation.

There are a number of parameters that can be measured to determine the extent to which a composting process has ended and the degree to which composted material has become stabilised. These include: oxygen uptake, carbon dioxide production and heat production.

Oxygen uptake rate
(Iannotti et al. 1993) developed a method involving taking 125 g of a compost sample at 50% moisture that is equilibrated in air in a water bath at 37º C overnight. After this, the oxygen uptake rate is determined over a one-hour period with the use of a dissolved oxygen meter.

Carbon dioxide production rate
One method for measuring carbon dioxide production rate (Bartha and Pramer 1965) involves taking a 25 g representative sample of compost, at 50% moisture that is equilibrated at room temperature for three days. The carbon dioxide production rate is the measured by incubating at 35º C and capturing the carbon dioxide in a sodium hydroxide trap over 5 days.

Heat production
(Brinton et al 1995) determined heat production by taking a representative 25 g sample of the compost at 50% moisture. This is then added to a Dewar flask and the amount of heat generated is determined over time at room temperature.

The results of these tests may not be easy to interpret. The microbial metabolism responsible for the production of all three parameters changes with time, the nature of the substrate, the oxygen levels, pH and temperature. One index of stability, the respiration rate, based on carbon dioxide production (mg CO_2-C/g compost carbon-day) has been published by Feldman (1995) and is summarised in the following Table. It is important that these results should be considered along with other measurements of compost maturity such as carbon: nitrogen ratio, pH, and nitrate levels.

Table 4:1: Compost stability index using carbon dioxide production rate
(From Feldman (1995)

Respiration rate	Rating	Characteristics
<2	Very stable	Well cured compost; No odours; No continued decomposition
2-5	Stable	Cured compost; Limited odour potential; Minimal impact on soil carbon and nitrogen dynamics
5-10	Moderately unstable	Uncured compost; Minimal odour production; Addition to soil may result in nitrogen immobilisation High toxicity potential Not recommended for growing plants from seeds
10-20	Unstable compost	Very immature compost; High odour and phytotoxicity potential; Not recommended for growing plants from seeds
>20	Unstabilised material	Extremely unstable material; Very high odour and phytotoxicity potential; Not recommended for use

4.8 The post-composting stage

The final stage is referred to as the post-composting stage. This often involves screening the compost into range of products of varying particle size. Oversized particles may be removed and put back into the composting process or disposed of.

5. OPTIMISING THE COMPOSTING PROCESS

For commercial, technical and environmental reasons it is important that composting is carried out under as near optimal conditions as possible. This will help to allow the manufacture of compost to be carried out profitably, with the efficient use of capital plant, labour and other resources. It will also help ensure that the process is carried out quickly and safely, and in a way that will produce as high a quality compost product as possible with the minimum effect on the environment.

Some optimisation methods involve the initial feedstock mixture, while others depend upon choosing the correct composting technology for the particular circumstances, and in operating that technology to maximum effect. The detailed methods chosen to optimise a composting process will very much depend upon the type of composting technology chosen. However, the following basic considerations apply no matter which technology is used.

Several of composting facility design and operating guides have been prepared to advise composters on how to design and run their operation most efficiently[4]. A number of other studies[5] take a more specific look at technical aspects of commercial composting, or at the way in which the compost procedure employed can affect the quality of the resultant compost, (Korner et al. 1997).

A further set of studies has used laboratory model methods[6] and mathematical or computer systems[7] to understand the composting process and to optimise its performance. Fuzzy logic has also been employed to predict the performance of composting systems, (Bhurtun and Mohee 1996).

The implications of many of these studies are considered later in this Section and in Sections 8 to 12 and 15 to 16

5.1 Formulation and feedstock

All of the factors considered later in this section, examined from the point of view of optimising the composting process, are affected by the original formulation of the feedstock at the start of the process (Lynch 1993, Richard et al. 1993, Richard and Woodbury 1994, Ammar 1996, Renzo et al. 1996, Savage 1996, Korner and Stegmann 1998). Many articles have been published on how to select and calculate

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[4] Anon 1991a, Anon 1991b, Finstein and Hogan 1993, Composting Council 1994, Strom 1994, Composting Council of Canada 1995, Resource Recycling Systems 1995, Anon 1996c, Croteau et al. 1996, Florida Department of Environmental Protection 1996, Goldstein 1996c, Haug 1996, Hollyer and Tyler 1996, Leege 1996, UNEP 1997, Washington State Department of Ecology 1997

[5] De Bertoldi 1992, Hoitink et al. 1993, Canet and Pomares 1995, Anon 1996b, Balis *et al.* 1996, Keener *et al.* 1996, Lopez-Real and Baptista 1996, Lynch and Cherry 1996, Michel and Reddy 1996, Muchel and Reddy 1996, Steuteville 1996b, Sela and Avnimelech 1997

[6] Miller 1984, Miller 1989, Hansen *et al.* 1993, Marugg *et al*. 1993, Michel *et al.* 1993, Narayan 1993, Pennington *et al.* 1995, Tseng *et al.* 1995, Atkinson *et al.* 1996, Baca *et al.* 1996, Dominguez *et al.* 1996, Elwell *et al.* 1996, Garcia *et al.* 1996, Miller 1996, Miller 1996a, Papadimitriou and Balis 1996, Piccinini *et al.* 1996, Razvi and Kramer 1996, Siebert *et al.* 1996, Silveira and Ganho 1996, Szmidt and Bryden 1996, Korner *et al.* 1997, Noble *et al.* 1997, Brinkmann *et al.* 1998, Day *et al.* 1998

[7] Whang and Meenaghan 1980, Nakasaki *et al.* 1987, Hamelers 1993, Haug 1993, Keener *et al.* 1993, Marrug et al. 1993, Vanlier *et al.* 1994, Das 1995, van der Werf 1995, Das and Keener 1996, Nielsen 1996a, Shaw and Stentiford 1996, Stombaugh and Nokes (1996), Bertoldi *et al.* 1997, Mohee *et al.* 1998

the correct formulation (Goldstein 1996, Michel et al. 1996a), the correct methods of sample collection and laboratory preparation (Leege and Thompson 1997, Anon 1998i), the chemical analysis of the feedstock, composting mixtures and composts (Stilwell 1993a, Leege and Thompson 1997, Anon 1998i), and the role that each feedstock component plays in the composting process (Whitney and Lynch 1996). A number of calculation aids have been produced (Cornell Composting 1997a, Cornell Composting 1997b, CRIQ 1997).

The importance of freedom from contamination of the wastes selected as feedstock, and the quality aspects of source-separated wastes versus mixed wastes, is well recognised, (Richard et al. 1993). It is essential that in the case of MSW feedstock, both mixed and source-separated, every effort is made to remove contaminants either before or after composting or to prevent them from entering the feedstock in the first place. The level of contamination of the MSW feedstock will determine the potential uses of the resultant compost.

5.2 Aeration

Composting is an aerobic process - one requiring adequate supplies of oxygen. Should the composting process ever become anaerobic, that is, should the supply of oxygen become insufficient, the process is compromised in a number of ways, and there is a considerable risk of offensive odours being generated. The guarantee of sufficient levels of oxygen in the composting environment, by adequate aeration, is therefore an important part of optimising the process (Nakasaki et al. 1992, Hartsock et al. 1994, Chalmers 1995, Brinkmann and Gahrs 1997, Brinkmann et al. 1998). The supply air is also used to remove water vapour and carbon dioxide from the composting waste, and to allow a degree of temperature control.

The provision of adequate aeration depends upon two components: the structure of the composting waste (Das and Keener 1996a), and the mechanism for the supply of air. This latter factor will vary with the composting technology chosen. It is essential that the composting waste should have sufficient void space to allow the oxygen in the air, however supplied, to reach the micro-organisms on the particles of the composting waste. This will also allow the escape of carbon dioxide produced during composting. The void space found in composting wastes is a function of the nature of the wastes themselves, the way in which these are shredded and mixed, the particle size of the shredded material, and the moisture.

The void space is also a function of the way that the composting waste is handled during the composting process, that is, whether the material is compressed, moved or agitated, or if there is a control over moisture. The selection of a composting technology will therefore have a considerable effect upon the void space that is available throughout the composting process.

Air can be supplied to the void spaces by means of turning (Michel et al. 1996a), natural convection, or by some form of forced air system, depending upon the composting technology chosen. A minimum of 5-15% oxygen is normally recommended. The optimal level of aeration in any particular situation will depend upon the activity of the composting mixture. Even though a composting mass may be aerated, there may still be significant anaerobic microbial activity taking place, (Atkinson et al. 1996a).

The supply of oxygen is also intimately related to the control of composting temperatures and the moisture of the composting waste. Too great a supply of air may cool the compost excessively or cause the compost to dry out. An effective aeration system will balance all of these requirements and also take into account any costs associated with the supply of air.

5.3 Moisture

The moisture of a composting mixture will have an important effect upon the efficiency of the composting process, (Nakasaki et al. 1992a, Stentiford 1995, Tiquia et al. 1996, Cornell Composting 1997a, Cornell Composting 1997c). The optimum moisture for composting will very much depend upon the water holding capacity of the composting mixture. Typical levels are between 50% and 70%.

If the moisture level is too high for a particular mixture the void spaces may be filled with water and aeration compromised. Unacceptable levels of leachate may also be produced with associated odour and water pollution problems, (Frink and Sawhney 1994, Wershaw et al. 1995). Considerable quantities of nitrogen and other nutrients may be lost as leachate. It has been suggested that compost leachate may be used as a fertiliser, (Frederickson 1997). If the moisture level is too low, microbial activity may be reduced and the composting process will slow. Problems with the release of bioaerosols may also occur. The control of moisture is also important from the point of view of minimising the risk of fire at a composting facility, (Riggle 1996a, Rynk 2000a, Rynk 2000b).

Although water is produced by the metabolic activity of micro-organisms involved in composting (Miller 1991), composting processes tend to have a drying out effect. Therefore, the starting moistures, and the degree to which moisture levels are measured and controlled during composting, have a very significant effect upon the efficiency of the operation. Different composting technologies vary greatly in their tendency to dry out compost. Different technologies will also vary in the ability to add water during composting, and in the ease with which moisture can be measured and controlled.

It is fairly straightforward to produce a starting feedstock mixture of the required moisture. The resultant moisture obtained by mixing two components (A + B) whose moistures are known is calculated as follows (Fitzpatrick 1993):

$$\%Moisture = \frac{(\text{Wt. H}_2\text{O, A}) + (\text{Wt. H}_2\text{O, B})}{\text{Total Wt.}}$$

The moisture of a three-component mixture is calculated by the following equation (Cornell Composting 1997d):

$$\%Moisture = \frac{((a * x) + (b * y) + (c * z))}{(x + y + z)}$$

Where a, b, and c are the moistures of the three components, and x, y and z are the corresponding weights.

A number of calculation aids are available to find the resultant moisture of mixing varying quantities of a number of different materials whose individual moistures are known (Cornell Composting 1997d). It is also possible to calculate the required weight of a third ingredient to produce a mixture of the required overall moisture when the moistures and weights of the first two components, and the moisture of the third component are known (Cornell Composting, 1997a). The formula used for this calculation is as follows:

$$Z = \frac{((g*x)+(g*y)-(a*x)-(b*y))}{(c-g)}$$

Where g is the required overall moisture, a, b and c are the moistures of the three components, x and y are the corresponding weights of the first two components, and z is the unknown weight of the third component.

5.4 Particle size and structure

The particle size of the material being composted is crucial in terms of the ability of air to penetrate the composting mass, and in supplying the maximum amount of surface area on which micro-organisms can act. If the average particle size is too great, composting can be slow because the available surface area is proportionally small. If the particle size is too small, composting can again be slow because of the difficulty of supplying sufficient quantities of air. The optimum particle size will depend upon the nature of the feedstock components and mixture, and the method of air supply and temperature control. Shredded woody type amendments or leaves (Elwell et al. 1994) are often added to control this parameter, although some systems do not add amendments (Elwell et al. 1998).

5.5 Compositional homogeneity

A variation in structure throughout a composting mixture, for example, a variation in particle size, or of moisture, or carbon to nitrogen ratio, can have a major effect upon the uniformity of the compost product and the speed of the composting process. The importance of this characteristic will depend very much upon the composting technology used. In some systems, the composting waste is mixed at intervals throughout the composting process and any initial heterogeneity may be corrected. However, in other systems the composting mixture is not moved or mixed once composting begins. Any initial heterogeneity in this situation can produce effects that last throughout the entire composting process and will be reflected in the quality of the compost product.

5.6 pH

The starting pH of a composting mixture will depend upon the nature and proportions of the components of the feedstock, and will vary throughout the composting process, typically within the limits of 6 and 8.5. The pH of a composting mixture is important in that each type of composting micro-organism has an optimum pH value for its greatest activity. The pH will also determine the solubility and availability of nutrients utilised by the micro-organisms and the extent to which any heavy metals in the mixture are soluble.

The pH of a composting mixture is not normally actively controlled. Exceptions include the addition of gypsum (calcium sulphate) to mixtures of cereal straw and animal manures used to make compost to grow the white commercial mushroom

Agaricus bisporus. The pH of the final compost product may be controlled by the addition of a number of chemicals such as sulphur.

5.7 Carbon source

Carbon is an important nutrient utilised by micro-organisms. The amount of carbon present in a composting mixture is therefore an important characteristic of the feedstock. However, not all of the carbon in the feedstock will be available to the composting micro-organisms. The availability of carbon is both a function of the type of micro-organism and the form in which the carbon is present in the waste. Micro-organisms show a very wide variability in the type of carbon that they can utilise, ranging from simple sugars to complex organic molecules such as cellulose and lignin. The types of micro-organisms utilising carbon, and the types of carbon molecules being utilised, will vary throughout the composting process. The more resistant forms of carbon, such as lignin, will tend to form the greater part of the final compost product.

An estimate of the amount of carbon in a feedstock component, a composting mixture, or a compost product can be calculated from the Volatile Solids (VS) content of the dried material. The VS component in an organic material is the fraction that is lost from a dried sample on combustion at 500-600°C. The VS component consists mainly of the elements carbon, oxygen, and nitrogen. The ash component consists mainly of the elements calcium, magnesium, phosphorus, and potassium. Adams et al. (1951) has determined that it is valid to assume that the carbon content of the VS component in many organic wastes is 55%. The carbon content of the material as a whole can then be calculated as follows:
% Carbon = (% Volatile Solids) / 1.8

5.8 Carbon: nitrogen and other nutrients

The ratio of carbon to nitrogen in the initial feedstock has a major effect upon the composting process (Switzenbaum et al. 1994, Bernal et al. 1996, Churchill et al. 1996, Cornell Composting 1997b, Cornell Composting 1997f, Korner and Stegmann 1998). Because of the methods commonly used to determine the carbon to nitrogen ratio (Kayhanian and Tchobanoglous 1992), it is often the total carbon present that is measured, and not the amount of carbon that is available to the micro-organisms. A typical ratio of carbon to nitrogen in a feedstock mixture is 30:1. If this ratio is higher, the composting process tends to slow. If the ratio is lower, excessive amounts of ammonia are often released, often with associated odour problems.

A number of sources of analytical data are available that list typical carbon to nitrogen ratios for a wide range of organic materials. Formulae are also available to allow the calculation of appropriate proportions of different feedstocks to provide an ideal starting carbon: nitrogen ratio. Feedstock components are then mixed to match this ratio. These calculations are particularly important in determining suitable feedstock mixtures for very high carbon: nitrogen materials, such as wood, woodchips, sawdust and paper, and very low carbon: nitrogen materials, such as some animal manures. The results of the calculations will significantly restrict the proportions of each of these materials that can be used in a feedstock mixture.

The ratio of carbon to phosphorus has also been found to be important in starting mixtures. In the case of MSW composting, a ratio of carbon: phosphorus of 120:1 to 240:1 was found to be advisable when the carbon: nitrogen is 30:1 (Brown et al. 1998).

During the composting process, carbon is lost in the form of carbon dioxide, and nitrogen is lost in the form of ammonia or in any leachate that is produced. More carbon is lost than nitrogen, and the carbon to nitrogen ratio therefore drops during composting to between 12:1 and 20:1. An attempt is often made to minimise the amount of nitrogen lost in the form of ammonia. This can be accomplished by adding calcium salts, such as calcium sulphate (gypsum), adding magnesium salts, or, more frequently, by a tight control over the carbon: nitrogen ratio of the initial feedstock mixture, (Witter and Kirchmann 1989, Moore et al. 1996, Carey 1997, Moore & Sauer 1998).

In addition to nitrogen, other major nutrients such as phosphorus and potassium, along with minor nutrients such as magnesium and calcium, and trace elements, are also required by the composting micro-organisms. In the great majority of feedstock mixtures, these nutrients are present in sufficient quantities and do not need to be added separately. This situation may not apply to a limited number of industrial or commercial organic wastes that predominantly consist of a single chemical compound. In these cases, any missing nutrients can be added by the addition of a suitable additional waste material.

A number of calculator and computer programs are available to assist in the calculation of the optimum starting mixtures in terms of carbon: nitrogen ratio. Fitzpatrick (1993) describes a program in the RPN language to calculate S, the number of pounds (or kilos) of an ingredient (A), that must be added to 1.0 pound (or kilo) of a second ingredient (B), in order to produce a mixture of the required carbon: nitrogen ratio. The basic equation is as follows:

$$S = \frac{\text{(C in 1.0 lb of B)-(Desired C:N)(N in 1.0 lb of B)}}{\text{(N in 1.0 lb of A)(Desired C:N)-(C in 1.0 lb of A)}}$$

A calculation aid is available for the determination of the carbon: nitrogen ratio of a three component mixture (Cornell Composting 1997e). The formula used is as follows:

$$R = \frac{(Q1(C1*(100-M1)+Q2(C2*(100-M2)+Q3(C3*(100-M3)}{Q1(N1*(100-M1)+Q2(N2*(100-M2)+Q3(N3*(100-M3)}$$

where:
R = carbon: nitrogen ratio of mixture
Qn = weight of material n
Cn = % carbon in material n
Nn = % nitrogen in material n
Mn = % moisture in material n

A spreadsheet solution to calculations involving moisture and carbon: nitrogen ratio of mixtures with up to four components is available (Cornell Composting 1997g).

5.9 Temperature

Temperature, along with the supply of oxygen, is one of the most important control parameters in composting. Each composting micro-organism has an optimum temperature at which it will operate effectively. Suitable temperatures vary from ambient (c. 25°C) up to 58-60°C, depending upon the micro-organism. If temperatures are too low, the activity of the micro-organisms will be reduced, while if too high, the micro-organisms may be killed. The optimum temperature for composting will vary according to the stage of that the composting process, and the type of micro-organism that predominates during that stage. During the early stages of composting the optimum may be 45-55°C, while during later stages when activity has decreased the optimum will be lower.

In many of the simpler composting technologies, there may be considerable variation in temperature across the profile of the composting mass. Temperatures at any one point in time may vary from ambient at the outside of the composting waste to above 70°C at the centre. Such a range of temperature will result in different micro-organisms being active, and therefore a variation in the nature of the compost produced in different parts of the composting mass.

The ability of a composting technology to allow the accurate measurement and control of temperatures over a long period of time, and throughout all of the composting waste, is therefore very important in operating at or near optimum conditions. Computer-controlled forced air systems are much more efficient at achieving optimum temperatures than systems that rely upon natural convection aeration.

Simpler methods of aeration control such as turning a fan on for 5 minutes every 30 minutes, or turning a fan on or off depending upon a simple temperature feedback system are also used. While these methods undoubtedly help to keep the composting process aerobic, they do not ensure that the process takes place under optimal or uniform aeration and temperature conditions.

Temperature control is also important in terms of ensuring that any human (Epstein 1993), animal and plant pathogens (Bollen 1993, Leege and Thompson 1997), and weed seeds that may be present in the feedstock are killed (Ponugoti et al. 1997, Tompkins et. al 1998). Tomkins et al. (1998) have shown that two weeks' windrow composting is effective at killing most weed seeds found in cattle manure, while four weeks composting killed all of the weed seeds studied. Epstein (1997) reviews the effectiveness of composting in the destruction of human primary pathogens in wastes and composts. The effectiveness of composting in destroying all types of pathogens, (human, animal and plant), is a function of both temperature and time. The USA Environmental Protection Agency (EPA 1994b) uses this temperature-time relationship as the basis of its Part 503 regulations governing the safe treatment of biosolids (sewage sludge cake).

Theoretically, a temperature of 55°C held for 3 days is effective as long as all of the composting waste is kept at this temperature for the entire period. In many simpler composting systems, this is just the temperature of the hottest part of the compost and other parts may be at much lower temperatures resulting in only partial pathogen kill. The use of a longer pasteurisation period such as 10 - 15 days, and periodic mixing of the composting waste, may only partly correct this situation, in that some parts of the compost may never be exposed to high enough temperatures for sufficient periods of time.

The detection of pathogens in finished compost can be carried out using a number of traditional microbiological techniques (Farrell 1993), and also more recent ones such as the use of PCR (polymerase chain reaction), (Pfaller et al. 1994, Blanc et al. 1997).

5.10 Microbial population

Many organic wastes contain sufficient numbers of the required types of micro-organisms to avoid the need to add additional micro-organisms to initiate and maintain the composting process, (Beffa et al. 1996, Palmisano and Morton 1996). Where the addition of micro-organisms might be required, for example when processing sterilised wastes, the micro-organisms are normally added in the form of another waste, such as an animal manure. A number of companies offer a variety of nutritional, microbial or enzymatic accelerators that are claimed to accelerate the compost process or to start the process more rapidly. The commercial benefit, from the composter's viewpoint, of a number of the accelerators has yet to be adequately proven.

A number of academic studies have looked at accelerating the composting process by the addition of microbial inoculants (Golueke et al. (1954), Gray et al. (1971), Poincelot (1975), Nakasaki et al. (1985), Nakasaki and Akiyama (1988), Faure & Deschamps (1991), Nakasaki et al. (1992)). Most of these studies showed little or no evidence for the beneficial use of microbial inoculants. Nakasaki et al. (1996) have looked at the addition of Bacillus licheniformis HA1 to accelerate the composting of specific organic wastes in a bench scale reactor. It was found that cell densities of B. licheniformis in excess of 2.0×10^4 cfu/g-ds were necessary to produce a measurable effect on the composting process.

6. COMPOSTING SYSTEMS - A CLASSIFICATION

There are several ideal physical, chemical and environmental composting technologies available by which the conditions can be attained to varying degrees. There is no single method of composting that is correct or optimal under all circumstances. The composting technology chosen will always depend upon a number of local parameters, such as the cost of competing organic waste disposal processes; the gate fee that can be obtained for receiving the feedstock; the availability of particular wastes; the location of the composting facility; the type of compost required by available markets; and environmental legislation.

The available technologies range from the very simple to the very sophisticated, (Stentiford 1993). In order to compare these technologies in terms of performance and environmental impact, a simple classification scheme is used. This is a modification of the chemical engineering approach used by Haug (1993). In this system, composting technologies are divided into two basic categories: those in which the composting process is carried out within some form of container, and those that are not. Composting processes carried out in a container may called ‘reactor’, 'in-vessel', 'contained', 'enclosed' ‘in-bay’ or ‘in-building’ systems according to the nature of the container and the degree of containment. The term ‘reactor’ should be restricted to a fully enclosed system. Composting processes not carried out within a container are referred to as 'open' or 'outdoors' systems.

Composting technologies may be further classified according to whether the composting waste is moved or not, if forced air is supplied, and whether the composting process is carried out on a continuous or batch basis. The following Figure summarises the classification:

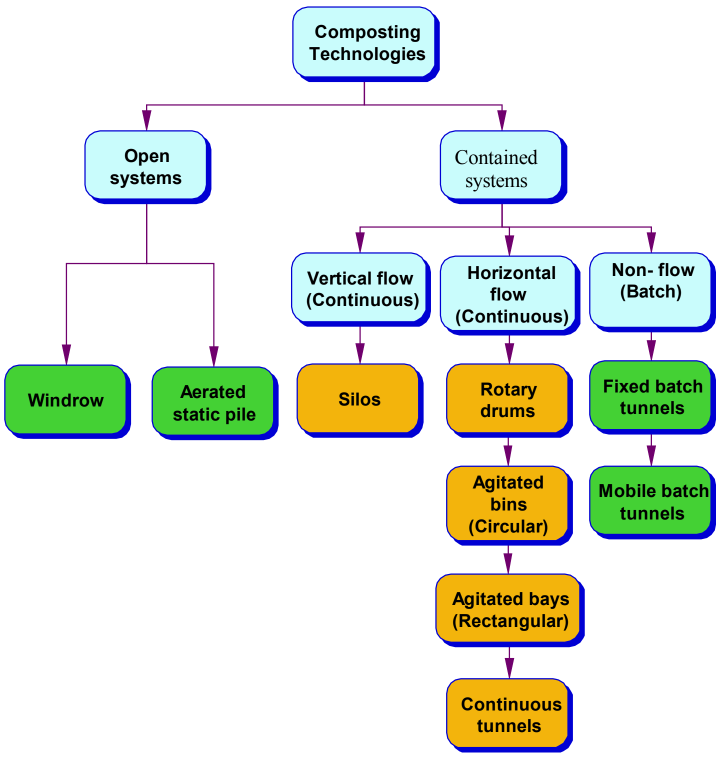

Figure 6-1: Classification of composting systems

This basic scheme can be elaborated as below to identify the main forms of commercial composting technologies currently available.

I. **Open systems**
   - A. Windrow composting
   - B. Aerated static composting

II. **Contained systems**
   - A. Continuous or intermittent composting systems - vertical flow (silos)
   - B. Continuous or intermittent composting systems - horizontal or inclined flow
     - i. Rotary drums
     - ii. Agitated bins or bays
       - a. Circular
       - b. Rectangular
     - iii. Continuous tunnels
   - C. Batch composting systems
     - i. Open bays
     - ii. Fixed batch tunnels
     - iii. Mobile batch tunnels

Composting technology is still in a process of development (Conti et al. 1996, Raninger 1996, Tardy and Beck 1996) and a number of technologies in use, or in development, may not neatly fit in with the above classification.

Each of these composting technologies will be considered later in this report. The technologies will be divided into open and contained systems using the same numbering system as that used in the above Figure. In each case, the theory of the technology will be discussed first and then examples of commercial systems using the various technologies will be examined.

7. THE PRINCIPLES OF OPEN COMPOSTING SYSTEMS

Before the more advanced contained composting systems are discussed, it is useful to examine the simpler open systems. These technologies clearly demonstrate the basics of composting and illustrate those areas of concern that are addressed, and in some cases solved, by the use of contained composting systems. Open composting systems are classified according to whether the composting waste is moved and mixed during composting. The two sub-systems, windrow composting and aerated static pile composting, along with some variations, are considered below. Both methods normally take place out of doors on a concrete pad or some other form of sealed surface such as lime-stabilised soil (Sikora and Francis 2000). Both methods can also be carried out in a building or under some form of protection from the weather.

7.1 Windrow composting [Type I A]

This is the commonest form of open composting system where the composting waste is mixed (turned) at intervals throughout the composting process. It is used in a large number of centralised composting facilities worldwide and is also the commonest technology used in on-farm composting (Anon 1998j, Majercak et al. 1998). It is by far the commonest composting technology currently used in the UK, (Composting Association. 1997, 1998). Windrow composting typically takes 12 to 20 weeks depending upon the feedstock used and the expected application of the compost produced (Curry 1997, Joint Services 1997c, Sela and Avnimelech 1997). There are many variations of the windrow process in use (Le Bozec and Resse 1987).

7.1.1 Construction of windrows

In windrow composting, feedstock material is shredded, if necessary, and then thoroughly mixed using a front-end loader or specialised mixing equipment. A typical shredder is shown in Figure 7.1.

Figure 7-1: Typical flat-bed shredder

After shredding and mixing the material is laid down in windrows (rows), either by the use of front-end loaders or specialised equipment. The dimensions of the windrows vary according to the type of waste being composted and the equipment used for turning, but should normally be 2 - 3 metres high by 3 - 5 metres wide (Rynk 1992). The length of the windrow is determined by the throughput of material to be composted. Lengths of 25 to 100 metres are common. The profile of the windrow in cross section can be square (as in the compressed windrows used to make compost for the commercial white mushroom), or trapezoid, semi-circular or triangular, where the windrows are typically not compressed. The profiles of windrows can change significantly during the composting process as the compost settles and as the volume and mass of the windrow decrease. As windrows reduce in size they may be combined to re-form windrows of the original dimensions.

7.1.2 Aeration of windrows

Forced aeration is not normal for windrow systems. Instead, natural convection aeration, sometimes referred to as the 'chimney effect', is relied upon. In natural convection aeration, hot, moist air rises through the windrow and draws in cooler, fresh air at the sides. If the windrows are within the size and shape ranges indicated above, and if the starting formulation, particle size and moisture are within correct limits, natural convection aeration can be a quite acceptable method of supplying oxygen to most, if not all, of the composting waste. If a windrow is too large, too wet, or too dense, natural convection aeration may well fail to supply sufficient oxygen, and anaerobic conditions may develop towards the centre and base of the windrow, with concomitant odour problems when the windrow is turned. If the windrow is too small, or not dense enough, so much heat may be lost that the required higher temperatures may not be attained and composting may slow or stop and pasteurisation may not occur. Oxygen levels in the windrow can be measured at the same time as temperatures using one of a number of hand-held devices.

7.1.3 Turning of windrows

Windrows are periodically turned by means of a front-end loader or a specially designed compost turner (Michel et al. 1996, Joint Services 1997b). An example of a specialised windrow turner is shown in Figure 9.2. This turning process supplies some additional aeration, although oxygen levels tend to drop to original levels within a few hours or less after turning. Turning also exposes fresh surfaces for composting by breaking up particles, makes the composting mixture more homogeneous, exchanges material on the outside of the windrow with material from the inside, opens up the structure of the material to produce air spaces, and releases heat, carbon dioxide and water vapour in the form of steam (Michel et al. 1996). Turning may also release significant quantities of bioaerosols (spores of bacteria, actinomycetes and fungi), ammonia, and, if the windrow is anaerobic in parts, it may also release significant quantities of offensive odours.

Figure 7-2: Typical side windrow turner

Turning is typically carried out once a week, or even once a day, at the start of the process and once every two weeks towards the end of the process. Water may be added during turning if the compost shows signs of drying out. There is considerable variation in the turning regimes employed in different composting facilities. The regime employed will depend upon the activity of the composting waste and a number of other production-related parameters.

Turning can be carried out either:

1. *in situ* - so that the windrow does not change position within the site while being turned;
2. with the longitudinal axis of the windrow moved laterally during turning and, in some systems, back to the original position during the subsequent turn; or
3. with the longitudinal axis of the windrow moved longitudinally during turning, and back to the original position during the subsequent turn.

For small windrow composting operations, it is common to use a front-end loader to both set up and turn the windrows. Front-end loaders are typically used to carry out the turning methods 2 and 3 outlined above. Front-end loaders can also be combined with manure spreaders to mix the material and to form new windrows. Front-end loaders provide a low cost, but not very efficient, method of turning.

Many different types of commercial windrow turning machines are also available. These turners carry out a much faster and more efficient form of mixing than front-end loaders, using any of the above 3 methods. These turners either may be driven by a PTO from a tractor or may be self-propelled.

Turners driven by a tractor travel in parallel to the windrow and may either completely straddle the windrow, or just turn one half of the windrow at a time. In the latter case the turner processes one side of the windrow and then turns the other side in a second pass. The turning mechanism can take the form of spinning flails, rotary drums with blades, or an inclined elevator that shaves off layers of the windrow and deposits it to one side to form a new windrow.

Self-propelled windrow turners are also available in a number of forms. Some of them provide both the turning action and the travelling action along the length of the windrows, while others just provide the turning action and are pulled or pushed by tractors or front-end loaders. The turning action can take the form of rotating flails, rotary drums with blades, inclined conveyors. Again, depending upon the turner design, the entire windrow may be turned in a single pass, or only one side.

The type of turning system employed will have a considerable effect upon the space requirements of the operation. Some systems, such as those using self-propelled straddle turners, require much less space between the windrows than others, such as tractor-propelled two-pass systems.

The purchase of a windrow turner represents a considerable investment, and care has to be taken that the capacity of the turner(s) matches the expected capacity of the composting site.

7.1.4 Screening

Unless the compost is to be landfilled or used for the most undemanding of applications, it is usual to pass the finished material through some form of screen. There are many different types of screen available, but the commonest is the rotating trommel screen shown in the following Figure. The screening action will separate the compost into a range of potential products, e.g. soil improver or mulch, based upon their particle size.

Figure 7-3 Typical trommel screen

7.1.5 The windrow composting site

The windrow process is best carried out on a concrete base with efficient control over any leachate (liquid runoff) produced by the composting. Typically, the concrete is laid so that it slopes slightly in one direction, c. 1:200, to guide any leachate into an underground sump. The collected leachate can either be pumped back onto the compost, or pumped into a tanker and removed from site. Some systems are set up on soil or hardcore rather than concrete. This approach cannot be recommended for general use within the UK because of potential problems with the leachate contaminating groundwater (Harper & Aleong 1998), contamination of the compost with soil or hardcore, and difficulty with vehicle movements during wet conditions. At least one windrow composting facility in the UK is using an asphalt base.

Most windrow systems are operated in the open air, although there are distinct process advantages in constructing the windrows under some form of cover such as a Dutch barn or a building. Providing cover in this way will protect the windrows from becoming too wet from rain and also reduce any potential leachate or odour problem. However, there are considerable cost implications in providing cover in this way and many current composting operations within the UK would not be able to bear the cost of such an improvement. Problems can also occur with a windrow system operated in a building from the steam and bio-aerosols generated, especially during turning. If windrow systems are properly constructed and managed, they can operate effectively without cover.

7.1.6 Organising and monitoring of a windrow composting process

If windrows are set up correctly, that is, with the appropriate dimensions, the correct formulation, homogeneity, moisture and particle size, it should be possible to turn the windrows according to a pre-arranged production plan. This will allow the most efficient use of labour and equipment. Where done, monitoring the composting process normally consists of a visual inspection of the windrows, the recording of temperatures, and the taking of samples for analysis.

Within the UK, windrow turning and process monitoring are organised in the first stage of the manufacture of mushroom compost by compressed windrow composting. Here, windrow turning is well organised and carried out to a strict production schedule. This is essential for an industry supplying a high quality and tightly specified product to its customers in a competitive market, without adversely affecting the local environment.

However, in most UK waste composting at the moment, the turning regime adopted is often in response to problems encountered during composting, such as the compost being too wet, too cool, too hot, or showing uneven temperatures. In some situations, turning is carried out according to the availability of labour and equipment rather than the requirements of a production schedule. Such procedures do not allow a cost-effective use of resources. Nor do they encourage the production of high quality compost to time and without affecting the local environment.

Several guides on how to set up, organise and optimise windrow composting and other types of composting facilities have been published, including: Rynk (1992), Composting Council (1994), Strom (1994), Composting Council of Canada (1995), Resource Recycling Systems (1995), Florida Department of Environmental Protection (1996), Haug (1996), Hollyer and Tyler (1996), Leege (1996), UNEP (1997), and Washington State Department of Ecology (1997).

These manuals and articles clearly outline the experience gained at many hundreds of windrow and other composting plants around the world, of widely varying sizes, using many different feedstocks. They recommend practical methods of setting up a composting facility, optimising the composting process in terms of financial viability and product quality, and minimising the effect of the process upon the environment. Many of those carrying out windrow composting in the UK have not had the advantage of the lessons provided in these documents.

The applicability of these reports to the situation in the UK will depend upon the type of material to be composted and the markets for the resultant composts. However, some general points in the reports apply to the setting up and operation of all composting facilities. These are summarised in Table 7.1:

Table 7:1: Recommendations for setting up and operating a composting facility

Factor	Recommendation
Approach to composting	Take a long term approach to the investment of time and money in setting up and operating a composting facility
Business plan	Prepare a detailed business plan for the composting facility exploring a number of possible scenarios, including changes in legislation and income from feedstocks and compost product.
Legislation	Be aware of existing and projected EU and UK legislation affecting the operation and financial viability of the composting option
Planning	Be aware of planning constraints concerning the setting up of composting facilities
Site location	Locate the composting site carefully, and sufficiently far away from sensitive receptors not to generate complaints.
Licensing	Be aware of waste management licensing regulations governing the operation of composting facilities
Environmental impact	Determine the effect of odours, bioaerosols, pathogens, potentially toxic materials, dust, noise, litter, vehicle movements, and leachate generated by the composting process on the local environment, and implement sufficient remedial measures.
Health and Safety	Be aware of all relevant Health & Safety legislation and ensure that the composting facility operates within these.
Feedstock	Ensure an adequate, long-term supply of suitable feedstock and ensure adequate quality control.
Process specification and operation	Produce a detailed production schedule for the composting process from the receipt of feedstock to the removal of finished product. This should ensure effective use of resources and minimise the effect of the process upon the environment.
Product specification and marketing	Determine the compost products to be manufactured and identify long-term markets.
Quality control	Determine and set up the correct quality control standards and tests for each stage of the process.
Site design	Design the site to work efficiently, to be safe, to not contaminate the local environment, and to be of clean appearance. Allow for possible expansion.
Good neighbour policy	Establish and maintain a close contact with the public, other companies, and regulators in the area.
Keeping informed	Keep informed of anticipated changes in legislation, standards, composting technology, and other matters affecting the operation of the facility
Training	Ensure all staff are sufficiently trained in all aspects of the operation of the site including Health & Safety.

Many of the detailed technical considerations in these guides have been considered earlier in this report in Section 7. It is strongly recommended that the above guides are examined in detail.

7.1.7 Strength and weaknesses of windrow composting

The strengths and weaknesses of windrow composting are summarised in Table 7-2.

Table 7:2: Strength and weaknesses of windrow composting

Feature	Comments
Temperature control	The temperature of the composting waste can vary significantly across the profile of the windrow leading to a variable compost product. There is little opportunity to take the composting waste through a pre-programmed temperature regime. Because the temperature (and other parameters) varies considerably throughout the windrow, the composting process is far from optimal and is normally quite slow.
Aeration control	The efficiency of natural convection aeration relies upon the windrows being of the correct shape, size and consistency. These change as the composting process proceeds. Some parts of the windrow may anaerobic. Aeration is not normally used as a means of accurate temperature control.
Moisture control	The composting waste tends to dry out as composting proceeds. It is difficult to replace this water precisely as required. There can be excessive drying of the surface of the windrows.
Particle size control	The initial required reduction in particle size is accomplished by shredding. Turning the windrows can be used to break up larger particles within the windrow thereby exposing new surfaces for composting. If the particle size is too small, air cannot penetrate through the windrow by natural convection aeration.
Structure control	Turning the windrows allows the reformation of air spaces within the composting waste.
Homogeneity	The varying temperature and moisture profile across the windrow introduces significant heterogeneity. The turning action allows the regular re-mixing of the composting waste to offset at least some of the problems with heterogeneity.
Pasteurisation	It is normally possible to produce temperatures in the bulk of the windrow high enough to provide adequate pasteurisation. There are regions within the windrow that will not reach pasteurisation temperatures. There is no guarantee that all of the composting waste is taken through a pasteurisation regime. This may limit the ways in which the resultant compost can be used.
Odour control	In uncovered windrow systems, there is a considerable risk of odours being released, especially during turning. Odour problems can be reduced to some extent by covering the windrows with specialised sheeting or by placing the windrows in a building with an air extraction and treatment system.
Bioaerosol control	Significant quantities of bioaerosols can be released during turning.
Data recording and analysis	Limited process data is available and this is normally manually recorded.
Manpower requirements and potential for automation	There is little opportunity for automation. Labour requirements for setting up, turning, monitoring, and breaking down windrows can be significant
Time required for composting	The duration of composting depends upon the feedstock used and the potential use of the finished compost. Typical composting times vary from 12 - 20 weeks, often followed by a period of curing or maturation.
Siting of facility	Because of potential problems with odour release in particular, it is essential that a windrow composting facility is situated a considerable distance away from residential buildings.
Capital cost	This is normally one of the least capital intensive of the composting options. The major capital requirements are for concrete, front-end loaders, turners and screens. The cost of laying new concrete can be a substantial part of the investment. It is common to use existing concrete areas.
Processing cost	This is normally one of the cheapest composting systems available in terms of processing cost per tonne of feedstock.
Area requirements	Significant areas are required for windrow composting.
Product quality	Compost quality is fairly low due to variation in compost structure, chemistry and microbiology. It may still be suitable for less demanding applications.

7.1.8 Variations of windrow composting

The form of open windrow composting described above is the commonest method of making waste-derived compost in the UK and elsewhere in the world. There are, however, several possible variations.

Windrows covered with porous sheeting
A number of companies offer semi-permeable materials to cover windrows during composting (see Appendices). A comparative study of the effect of using some of these has been undertaken by Kuhner and Fischer (1997).

Extended windrow composting
In some facilities very wide windrows, or even a single block of compost many metres square, are used in preference to the narrow windrows described above (Kayhanian et al. 1996). It is doubtful whether such block achieve adequate aeration.

In-building windrow composting
In some facilities, windrows are set up within sealed building, often in an attempt to avoid odour problems. Air may be extracted from the building and processed to remove odours before being released to atmosphere. Problems can occur with a build up of bioaerosols and/or steam within the building under these conditions.

7.2 Aerated static pile composting [Type I B]

This is the commonest form of open composting system where the composting waste is not mixed or turned during composting (Sikora et al. 1981, Roig and Bernal 1996, Williams et al. 1996, Joint Services 1997, Sesay et al. 1997, Block 1988). It is commonly used in many countries, but not, so far, to any significant extent in the UK. Aerated static pile composting typically takes 8 to 20 weeks depending upon the feedstock used and the expected application of the compost produced.

7.2.1 Construction of an aerated static pile

Once the feedstock for composting has been selected, shredded if necessary, and thoroughly mixed, it is formed into shapes similar to the windrows discussed above using a front-end loader. The structure is carefully managed to ensure that air spaces are maintained in the composting mass without the need for periodic turning. The composting mixture is placed on top of a perforated pipe or pipes, a perforated pavement, or diffusion plates that are linked to a fan. Once formed, the pile is not mixed or turned until composting is complete. The pile is typically covered with a layer of mature compost, about 15 - 30 cms thick, to prevent the outer surface of the pile from drying out, and to limit any release of odour. This layer can also allow even the outside layer of the composting wastes to reach the higher temperatures required for complete composting and pasteurisation.

7.2.2 Aeration

Air is supplied by means of a fan or blower, and is distributed more or less evenly throughout the pile in a perforated pipes or a perforated pavement (Fernandez and Sartaj 1997). Air can be supplied either by blowing air (forced aeration) or sucking air (induced aeration) through the pile. The system aeration is commonly controlled by a simple feedback mechanism using temperature or oxygen levels as the controlling parameter. An even simpler variation uses a timer to turn the fan on for fixed periods every hour or every day. The use of forced air in this way can produce a more uniform temperature profile across the pile than that found with windrow composting. The air supply also offers a degree of temperature control , and can ensure that oxygen levels do not drop below predetermined levels. The use of forced air can also allow the construction of rather larger heaps than with windrow composting, with a correspondingly smaller requirement for land. If air is sucked through the pile rather than blown, it is possible to pass the odour-carrying air through a simple biofilter in order to reduce the potential for odour problems.

A study (Fernandez and Sartaj 1997) has looked at a variety of aeration methods for aerated static piles: passive aeration (piles constructed over perforated pipes but with no fan system), forced aeration (piles constructed over perforated pipes with a fan system) and natural convection aeration (no perforated pipes or fans used). Considerable differences were found in the composting process with changes in the aeration method. The aerated static pile method can be significantly improved by the incorporation of a moisture monitoring and control system (Robinson and Stentiford 1993).

Sesay et al. (1998) examined the composting of municipal solid wastes by aerated static pile composting using both forced aeration and a hybrid of forced and induced aeration with temperature feedback control. It was found that the alternating air supply direction in the hybrid system produced a more uniform temperature throughout the composting waste. The hybrid system also brought about a smaller reduction in moisture and avoided the premature limitation of composting activity through the material becoming too dry. The hybrid system also caused a more rapid reduction in the number so pathogens in the composting waste than did the forced aeration system. The forced aeration system produced a slightly more stable compost product. Carucci et al. (1999) also tried an aerated static pile composting system that used alternate forced and induced aeration to process commercial vegetable waste and garden waste. Adequate stabilisation was achieved by 5 days composting followed by 4 weeks maturation.

7.2.3 The aerated static pile site

In many ways, the type of site required for an aerated static pile composting facility is similar to that for windrow composting described above (Rynk 1992). A large area of drained concrete is needed and there are advantages in placing the piles under cover although this is not absolutely necessary.

7.2.4 Organisation and monitoring of an aerated static pile site

As aerated static piles do not require turning, the organisation of the composting process is rather different. Most activity takes place setting up of the piles and taking them down when composting is completed. The monitoring and analysis of oxygen and temperature data, and the operation of the fans, can be partially automated.

7.2.5 Strengths and weaknesses of aerated static pile composting

The strengths and weaknesses of aerated static pile composting are summarised in Table 7.3:

Table 7:3: Strengths and weaknesses of aerated static pile composting

Feature	Comments
Temperature control	The temperature of the composting waste can vary across the profile of the pile leading to a variable compost product. However, there is a potential for greater degree of control compared to turned windrow systems. It is possible to take the composting waste through a pre-programmed temperature regime. Because the temperature (and other parameters) varies throughout the pile, the composting process is far from optimal and is normally quite slow.
Aeration control	The efficiency of forced aeration tends to be greater than that found in turned windrow systems. Aeration can be used to control temperature.
Moisture control	The composting waste tends to dry out as composting proceeds. There is little opportunity to replace this water as required, unlike in turned windrow systems. However, the covering layer of mature compost can significantly reduce surface drying.
Particle size control	As the piles are not turned there is no opportunity to reduce the size of larger particles within the pile or to expose new surfaces for composting during the composting process. If the particle size is too small, air cannot penetrate through the pile, even using forced aeration.
Structure control	As the piles are not turned there is no opportunity to reform air spaces within the composting waste.
Homogeneity	The varying temperature and moisture profile across the pile introduces some heterogeneity. Unlike in turned windrow systems there is no opportunity to correct this problem by turning at intervals.
Pasteurisation	It is normally possible to produce temperatures in the bulk of the pile high enough to provide adequate pasteurisation. The insulation effect of using of a covering layer of mature compost extends the high temperatures throughout the composting waste. There is no guarantee that all of the composting waste is taken through an appropriate pasteurisation regime. As no mixing occurs once the piles are set up, there is no opportunity to move material from a cooler to a hotter part of the pile.
Odour control	The covering of the piles with mature compost composts, and the use of a biofilter with induced aeration, can reduce risk of odour problems. This aspect of the process is much better controlled in aerated static piles than in turned windrows.
Bioaerosol control	As the compost is not moved during processing, unlike in turned windrows, bioaerosol production remains minimal. Bioaerosols can be released during the final break up of the pile.
Data recording and analysis	It is normally possible to monitor and analyse oxygen and temperature data much more easily than with turned windrows.
Manpower requirements and potential for automation	There is little opportunity for automation except for aeration. Labour requirements for setting up and breaking down the piles can be significant, but are minimal during the composting process itself.
Time required for composting	The duration of composting depends upon the feedstock used and the potential use of the finished compost. Typical composting times vary from 8 - 20 weeks, often followed by a period of curing or maturation.
Siting of facility	Because of potential problems with odour release in particular, it is essential that an aerated static pile composting facility is situated a considerable distance away from residential buildings.
Capital cost	This is normally one of the least capital intensive of the composting options. The major capital requirements are for concrete, front-end loaders, and aeration equipment. The cost of laying new concrete can be prohibitive.

Feature	Comments
Processing cost	This is normally one of the cheapest composting systems available in terms of processing cost per tonne of feedstock.
Area requirements	Significant areas are required for aerated static pile composting but the process can require less space per tonne input than windrow composting.
Product quality	Compost quality can be reasonably high as long as the feedstock mixture is correctly formulated, the pile is adequately insulated, and the aeration system is properly designed and operated.

7.2.6 Variations of aerated static pile composting

Extended area static pile composting

In some circumstances, a large block of compost many metres square is constructed on top of perforated pipes or a perforated pad, instead of the narrow piles described above (Rynk 1992). This is claimed to offer a more efficient use of concrete space.

Passively aerated static pile composting

Static piles have also been constructed on loose straw, wood chips or on perforated pipes open at both ends (Lynch and Cherry 1996, 1996a). The intention is to encourage air to move through the heap of compost without the cost of a forced aeration system. Although this system certainly allows a more free movement of air it does not offer the same degree of controlled aeration, or control of temperature, that forced or induced air systems offer.

7.2.7 Comparison of windrow and aerated static pile composting systems

Both turned windrow and aerated static pile composting systems are popular ways of composting large quantities of a wide range of organic wastes. They are also successful methods as long as they are correctly managed and thoughtfully sited. Each method has advantages and disadvantages, and each has its supporters and detractors. It is difficult to make generalised comparisons between the two systems as each is carried out in a wide variety of ways, and with varying degrees of skill and recognition of the environmental implications. However, the main consequences of the two different approaches are as follows.

The turned windrow method can, to a degree, be regarded as more forgiving than the aerated static pile method in terms of the ability to modify and correct the mixture and process each time the windrow is turned. For example, during turning:

- water can be added to increase moisture;
- drier feedstock can be added to decrease moisture;
- high-nitrogen materials, carbohydrates or other additives can be mixed in with the composting waste;
- the dimensions of the windrows can be modified to improve aeration, or windrows may be combined towards the end of the process to conserve space; and
- the number and timing of turns can be changed to fit in with process requirements and other factors.

On the other hand, with aerated static piles it is essential that the initial mixture is as near optimal as possible as there is little opportunity to correct errors, such as mistakes in formulation, thereafter.

Once an aerated static pile is set up, the rest of the composting process can be semi-automated by the use of a simple feedback system that controls the operation of the aeration system. In comparison, with windrow composting a physical intervention, with an associated cost, is required each time the windrow is turned and reformed.

The windrow turning process requires the extensive use of a front-end loader, or the purchase and use of an expensive windrow turner, with an associated driver. Once a static pile is set up, no mobile plant is required and the labour requirements, apart from monitoring, are minimal until the composting process is completed.

It is normally accepted that aerated static pile systems require a rather smaller area of concrete, per tonne input of feedstock, than windrow composting. The actual space required very much depends upon the relative dimensions of the windrows and static heaps, the width of the isles between the windrows or piles, and the operating area required by the equipment used to turn the windrows. The fact that aerated static pile composting can be somewhat faster than windrow composting may reduce the space requirement for the static pile system. However, this potential reduction in composting time with aerated static pile systems is not always found in practice. If older windrows are merged, to compensate for material shrinkage during composting, the area required for windrow composting is reduced.

The lengths of time required by each method to bring composts to the same stage are difficult to compare as they depend to a great extent upon the efficiency of the operator and the degree of expertise applied. Both methods tend to require much longer periods of time to reach a particular stage than the more intensive, contained composting methodologies.

The quality of the resultant compost produced by the two methods will in each case depend upon the quality of the feedstock, the efficiency of the composting regime applied, and the quality of the management. Both methods are capable of producing compost of a quality suitable for a range of beneficial uses, and both are also capable of producing very poor quality compost.

Windrow composting is sometimes associated with odour problems, particularly at the time of turning. While many of these problems can be completely avoided by proper siting of the composting facility and by proper management of the composting process, it remains true that the mixing and movement of hot compost in the open air can be potentially problematic. Properly managed aerated static piles can be less of a problem in this regard for the following reasons:

- the composting waste is not disturbed while it is hot;
- the composting waste is covered by an insulating layer of compost that can also act as a biofilter; and
- aeration can be accomplished by sucking air down through the pile, passing it through a biofilter before release to atmosphere, and thereby preventing the release of odour-carrying air.

The capital costs and running costs of the two methods are both low compared to many other composting systems. In its simplest form windrow composting can be carried out by the use of a shredder and front-end loader on a concrete pad. In its simplest form the aerated static pile method can be carried out by the use of a shredder, a front-end loader and a simple aeration system with feedback control. Both systems are capable of a greater degree of sophistication. Which of the two methods is the more cost effective will depend upon a number of local factors, including the cost of labour, the cost of land suitably far enough away from residential buildings, the need to protect the compost from rain, and the need to implement odour-prevention schemes.

Within the UK there is no significant use of aerated static pile composting systems at the present time: windrow composting predominates. This situation appears to be the result of a lack of awareness of the potential usefulness of aerated static pile systems rather than a rejection of the technology on technical, cost or environmental grounds.

8. COMMERCIAL OPEN COMPOSTING SYSTEMS

A number of commercial windrow and aerated static pile composting technologies are available that are said to offer improvements over the basic methods.

8.1 Commercial covered windrow systems

A number of commercial windrow systems are available in which the windrows are covered by a semi-permeable material.

8.1.1 Sandberger GmbH (Austria)

In this system, shredded and mixed organic feedstock is made into windrows about 3 metres wide and 1.5 metres high. A semi-permeable cover, (TopTex), made from polypropylene felt, is then used to cover the windrows. The intention is to prevent the windrows from becoming too wet through rain or too dry through evaporation. The material is also thought to reduce the production of rain-generated leachate from the windrows by 75%. Although rain does not penetrate the Top-Tex material, gas exchange between the compost at the atmosphere is said not to be compromised. The cover is removed and re-applied to the windrow during turning by means of a modified turner.

Figure 8-1: Sandberger system with covered and uncovered windrows

8.1.2 GSI Environment (Canada)

This company offers a non-woven agrotextile material (BIOTEX) that is permeable to air but impervious to water. It can be applied to, and removed from, windrows by modified turners. The material is said to retain heat within the compost and to prevent the compost from becoming too wet through rain without preventing free gas exchange between the compost and the atmosphere. It reduces leachate production and is also said to reduce the risk of anaerobic conditions being generated by preventing the compost from becoming waterlogged.

8.2 Commercial aerated static pile systems

A number of commercial aerated static pile systems are available in which the piles are covered by a semi-permeable material.

8.2.1 Gore (W.L.) and Associates (Germany)

GORE-TEX is a three-layer plastic laminate with a PTFE central membrane that is waterproof and air permeable. It can be used to cover composting waste in order to retain heat, reduce over-wetting through rain, to reduce surface drying. It is said to contain malodours, remove the requirement for frequent turning, and to speed up the composting process. Air can be supplied to composting waste covered in this way by perforated pipes.

Figure 8-2: Gore-Tex covered aerated static pile

8.2.2 Typical sites:

Vogel Kompost: Baden-Baden - 12,000 tpa of green waste
Abfallwirtschaft Kreis: Lampertheim-Huttenfeld – 8,000 tpa of MSW

8.2.3 Ag-Bag International Ltd. (USA)

The Ag-Bag composting system incorporates a hydraulic ram that pushes shredded and mixed feedstock through a filling chamber into an EcoPOD (Preferred Organic Digester) plastic tube. This can be either 1.5 or 2 metres in diameter and up to 60 metres long. The filling process is repeated until the EcoPOD tube is full. The tube is fitted with a perforated pipe to provide aeration. This is placed inside the EcoPOD as it is being filled. The filling system is also fitted with an inoculum applicator to supply starter bacteria. Various sizes of systems are available according to the volume of feedstock requiring processing.

Figure 8-3: Ag-Bag composting POD

The advantages claimed for this method of composting over windrow composting and basic aerated static pile composting include a much reduced space requirement, reduced odour release, reduced leachate production and no need to turn the compost. The system is also said to be essentially independent of adverse weather conditions.

Typical site:
Plymouth City Council: Source separated household waste

8.2.4 Thoni Industriebetriebe (Austria)

In the Thoni AirRail system shredded and mixed organic feedstock is formed into trapezoid piles on top of covered aeration pipes set into asphalt or cement. A computer controls the supply of air from a fan and records processing data. The piles can also be covered by waterproof and air-permeable sheeting in an attempt to reduce odour release, retain heat and control moisture.

9. THE PRINCIPLES OF CONTAINED COMPOSTING SYSTEMS

The types of contained, reactor, or in-vessel composting systems described below indicate the widely different approaches taken to avoid some of the problems encountered with windrow and aerated static pile composting, such as slow processing, large area requirements, variable temperatures throughout the compost, lack of guarantee of pasteurisation, and the potential to produce and release odours and bioaerosols.

Several general articles on the principles of contained composting systems have been published, (Ferrero 1978, Anon 1982, Anderson et al. 1984, Anon 1986, EPA 1987, EPA 1989, Anon 1990, Riggle 1990, de Jong 1992, EPA 1996, Joint Services 1997a, Kern and Wiemer 1997, Edwards 1998, Hochstin 1998, Rynk 2000). The main conclusions of these studies are discussed in the following Sections.

9.1 A summary of the potential advantages of contained composting systems

If composting is carried out within a container, rather than in an open environment, such as with windrow or aerated static pile composting, it should be possible to obtain a number of advantages, including some or all of the following depending upon the exact composting technology chosen:

- control of the environment of the composting micro-organisms so that they may operate in a controlled way at or near optimum conditions;
- significant reduction in the time needed to take composting to a particular stage;
- predictable and cost-effective production schedule;
- clearly defined and demonstrable pasteurisation stage;
- compost product with predictable, uniform and quality controlled properties;
- detailed records of the composting process;
- avoidance of anaerobic conditions with a reduction or elimination of anaerobic odours; and
- control of odour-carrying, and bioaerosol-carrying, air.

The degree to which these advantages are in practice obtainable from the various composting technologies available will vary greatly from one technology to another.

9.2 The design principles of contained composting systems

The various composting technologies considered below share a number of common aims in their design, in an attempt to obtain the advantages indicated above.

9.2.1 Containment of feedstock

In order to take advantage of the greater control made possible by a contained system the composting feedstock has to be contained. This may accomplished in a number of ways, such as:

- containment of an open process within a building;

- containment within open-topped concrete bays inside a building;
- containment within a sealed concrete or steel vessel with continuous input of feedstock and output of compost; and
- containment of individual batches of feedstock within a sealed concrete or steel vessel.

9.2.2 Independence from the environment

Open composting systems can be greatly affected by changes in temperature, the occurrence of heavy rain, and by very dry or windy conditions. These effects can range from a slow down or cessation of the composting process to the occurrence of odour, leachate or bioaerosol problems. A contained system helps isolate the composting process from changes in the local environment.

9.2.3 Increased speed of operation

Windrow and aerated static pile composting take a considerable time. Periods of 8 - 20 weeks or longer are common. Much of this extended period is caused by the composting micro-organisms operating under less than optimal conditions, by temperature and aeration variations across the profile of the composting heaps, and by the effects of local weather conditions. Designers of contained systems seek to remove these sub-optimal conditions and thereby speed up the composting process considerably.

9.2.4 Reduced facility foot print

Open composting systems occupy large areas of land. As this land is often covered with concrete there may be considerable cost implications. A contained system should be able to process an equivalent quantity of feedstock in a much smaller area.

9.2.5 Production schedule control

The cost of processing a tonne of feedstock varies not only with the composting technology chosen but also with the efficiency with which the composting operation is carried out. A very important factor in cost control is the effective use of labour and equipment. This is only possible if a cost-effective production schedule can be operated using all resources in the most efficient way. Open composting systems are subject to so many variables (see above) that many open composting facilities do not operate to a controlled and predictable schedule. A contained system should be more amenable to tight process control.

9.2.6 Guaranteed aerobic conditions

Odour problems caused by the creation of anaerobic conditions are discussed elsewhere in this report. They are often the most important problems encountered by a composting facility. It is very difficult, if not impossible, to guarantee aerobic conditions throughout all of the material composted by a windrow, or even by an aerated static pile, composting system. The designer of a contained composting system seeks to guarantee that all of the composting waste is exposed to a minimum level of oxygen (c. 5 -15%) throughout the entire composting process. The mechanism by which this is carried out varies, but normally involves the use of a forced air supply linked to an oxygen and/or temperature probe.

9.2.7 Effective and uniform temperature control

Waste material naturally goes through a range of temperatures in composting before a final compost product is produced. In open systems there is a considerable range of temperatures throughout the composting heap at any one time. The control of these temperatures by the operator is essential in order to carry out a rapid composting process producing a uniform and predictable compost product. A contained system seeks to guarantee that all of the composting waste is at the same temperature at any one time, and that this temperature is under direct control of the operator. The composting waste can then be taken through a pre-determined temperature regime with considerable accuracy.

9.2.8 Guaranteed pasteurisation

Many of the organic wastes used in composting contain significant levels of human, animal and plant pathogens, as well as viable weed seeds. It is essential that these are killed during the composting process, or that their number per gram of compost is brought down to acceptable levels. Contained systems, through the control of temperature (see above), and efficient insulation, seek to guarantee that at one stage of the composting process all of the material is taken through a temperature regime, for example 55°C for 3 days, that results in an effective pasteurisation.

9.2.9 Efficient leachate control

Open systems that are exposed to the environment can produce odour and containment problems through the release of leachate. A contained system reduces the production of leachate and contains, recirculate or otherwise control leachate that is produced.

9.2.10 Efficient odour control

Because the composting process is contained, a contained, it is possible to ensure that any odour-carrying air generated is processed to remove odours before it leaves the composting container. Different contained composting technologies vary considerably in their ability to accomplish this. The optimal methodology is normally to minimise the amount of air requiring treatment, to take that air through a wet scrubber to remove ammonia and to cool the air, and then to pass the air through a biofilter to remove other odour producing chemicals.

9.2.11 Efficient bioaerosol control

Much work has been carried out in recent years on the health implications of bioaerosols generated while organic wastes are composted (Breum et al. 1996, Malmros 1996, Messner and Mark 1996, Sigsgaard et al. 1996) for composting and at composting facilities themselves, (Millner et al. 1994, Gillett 1992, Gumoski et al. 1992, Beffa et al. 1995, Beffa et al. 1995a, Haines 1995, Fischer et al. 1995, Millner 1995, Epstein 1996, Fischer et al. 1996, Messner and Mark 1996, van der Werf 1996, Beffa et al. 1998).

The general conclusions of the major report by Millner (1995) can be summarised to indicate that:

the general population is not at risk to systemic or tissue infections from compost-associated bioaerosol emissions;

immunocompromised individuals are at increased risk to infections by opportunistic pathogens, such as *Aspergillus fumigatus*, which occur not only in compost but also in many other organic materials in the environment;

asthmatic and allergic individuals are at increased risk to responses from bioaerosols from a variety of environmental and organic sources, including compost; and

occupational exposure to bioaerosols on composting sites may be significant, depending upon the individual site, operational characteristics, and worker proximity. Adverse health effects are not generally observed but have been seen in some workers in mushroom composting facilities and where wood chips and bark are composted.

The UK Composting Association has published a guidance note on bioaerosols (Composting Association 1998), and a standardise protocol for the sampling and enumeration of airborne micro-organisms at composting facilities, (Composting Association 1999). Much data on this topic has also been generated in the mushroom composting industry (van den Bogart et al. 1993)

Open composting systems, especially during turning, dry conditions or at the end of the composting process, can release considerable quantities of bioaerosols. Just as a contained system seeks to contain and process exhaust gases to prevent odour problems, the air can be similarly contained and processed to prevent spores escaping from the composting container into the environment.

9.2.12 Appropriate data collection and analysis

As with any other manufacturing process, it is essential that adequate production data is collected. This enables the process to be quality controlled, for example to prove that a particular batch of material has been adequately pasteurised. Monitoring enables trends and problems to be identified. It is much easier to collect data from a contained process, where the composting waste and its immediate environment should be under uniform and controlled condition, than from an open system where non-uniform conditions exist. As most contained systems are under computer control, the same computer can often be used to collect, analyse, display, and store the data in the most useful way.

9.2.13 Compost quality control

If a contained system is able to control aeration, temperature and pasteurisation adequately it is possible to produce a safe, uniform, tightly specified compost product. This is a vital requirement if the compost is to be sold into any but the least demanding of markets.

9.2.14 Cost-effective expansion

Composting facilities are often constructed on a small scale initially and are then expanded as composting becomes more accepted in a country, as legislation changes, or as the business experience of the composter increases. Any composting technology employed, especially the more capital-intensive technologies, must be capable of being expanded in a cost-effective way. Modular contained systems therefore have an advantage over the single-sized systems for this aspect.

9.2.15 Minimum labour costs

Labour costs form a major proportion of compost processing costs. Any system that reduces the requirement for labour, without compromising safety and quality, is favoured. Many of the contained composting systems available, through the use of automation and computer control, can process large quantities of organic wastes with a very small labour requirement.

9.2.16 Efficient and cost effective management

Composting can only be cost effective and profitable if the process is managed efficiently. While this is normally carried out by managers working at, or close to, the composting facility, contained systems also sometimes offer the additional possibility of remote management. Through the use of modems, processing information can be transmitted to a central point where the data can be analysed and used remotely to monitor and control the composting process or to generate quality control data. This remote management may be carried out by the central management of a company to allow oversight of more than one facility. It may also be carried out by the suppliers of the composting technology, or by a consultant, to check for, and to correct, breakdowns in the process.

9.2.17 Summary of the aims and principles of contained composting

The aims and principles of contained composting can be summarised in the following Figure:

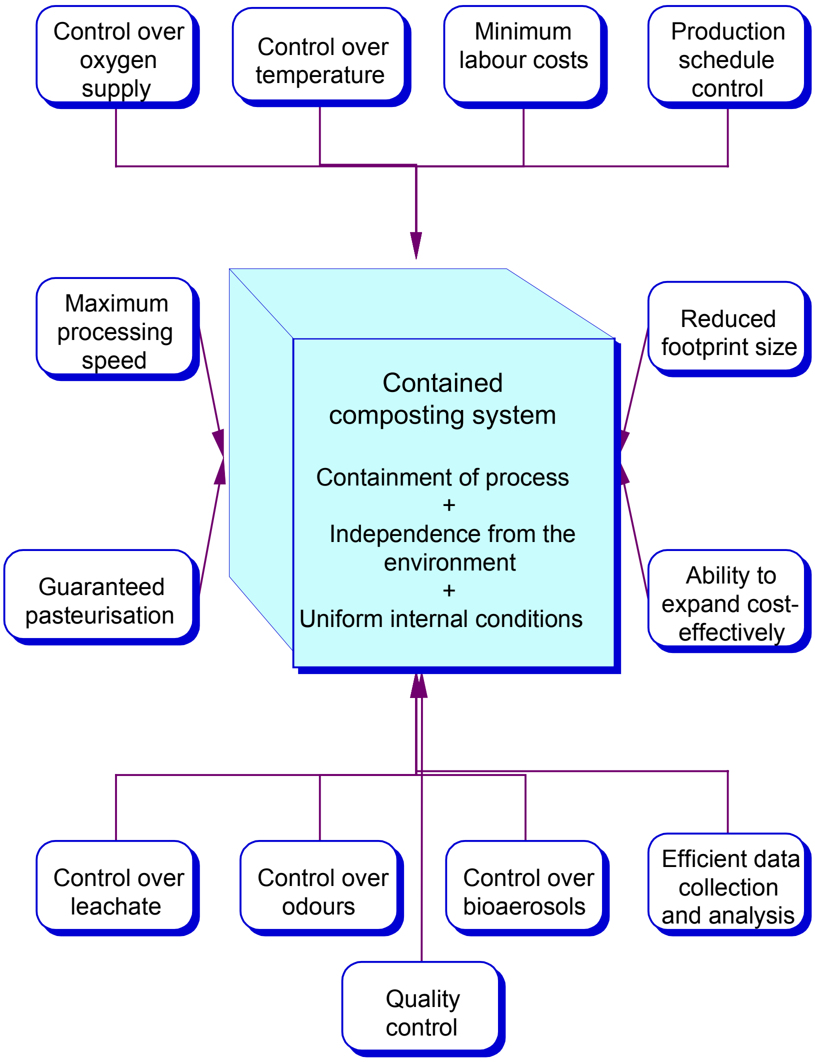

Figure 9-1: Aims and principles of contained composting

9.3 Vertical flow continuous composting systems [Type II A]

9.3.1 Schematic of vertical flow systems

A schematic for a typical vertical flow contained composting system is shown below. Not all systems have all of the attributes shown.

Suitably prepared feedstock is fed on a continuous or intermittent basis into the top of the reactor (silo). It then travels downwards and leaves the reactor, again on a continuous or intermittent basis. In some systems, the material is agitated as it travels downwards.

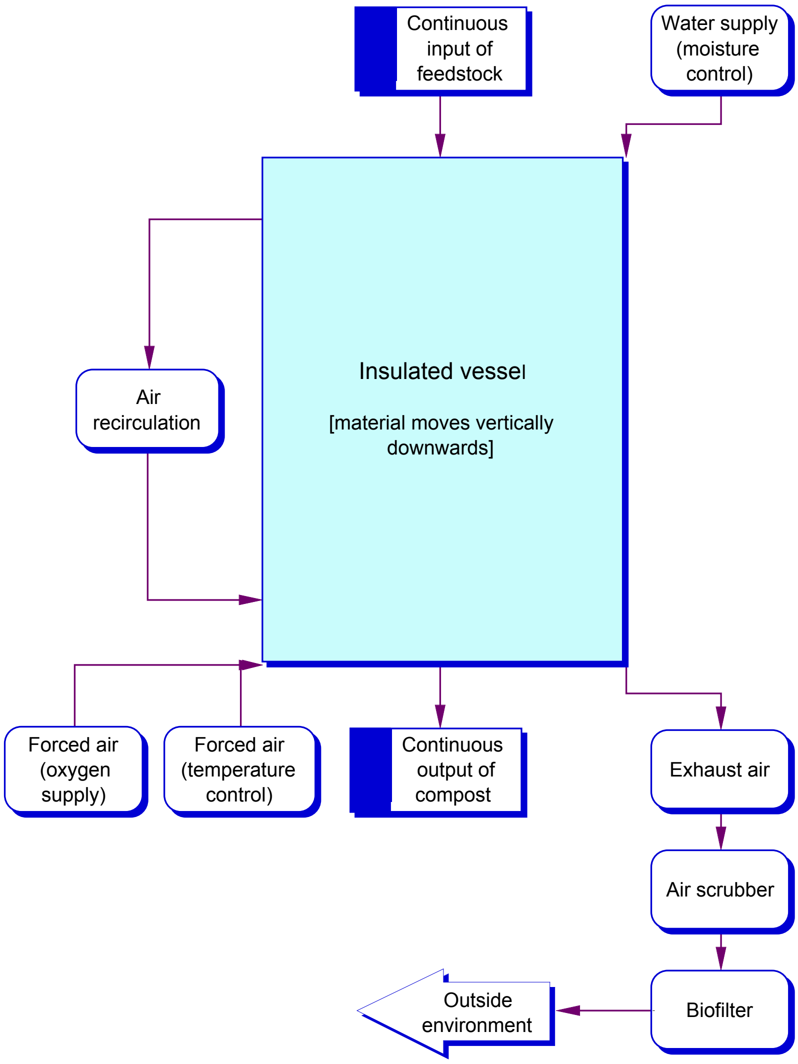

Figure 9-2: Typical vertical flow system

Air from the vessel has to be removed and passed through a scrubber and biofilter to remove odours.

9.3.2 Strength and weaknesses of vertical flow composting

The strengths and weaknesses of vertical flow composting are summarised in Table 9-1. As there is considerable variation between the many different types of vertical flow composting systems some of the comments may not apply to all systems.

Table 9-1: Strength and weaknesses of vertical flow composting

Feature	Comments
Temperature control	The common use of agitation and forced aeration, and the containment of the composting process, provide the potential for a much higher degree of temperature control than with open systems. There is often the ability to take the composting waste through a pre-determined temperature regime and to carry out the process at nearer optimal conditions.
Aeration control	The efficiency of aeration possible in the various forms of vertical flow varies considerably. However, the potential exists for a system much improved over the open composting systems.
Moisture control	There is often the facility to control moisture during the composting process by adding or recirculating water.
Particle size control	The initial required reduction in particle size is accomplished by shredding. The movement of the material through the composting system may also result in further particle size reduction.
Structure control	The continuous movement of material through the system can result in the reformation of air spaces.
Homogeneity	If the feedstock mixture is kept uniform a vertical flow system produce an homogenous end product.
Pasteurisation	It may be possible to take the material through an effective pasteurisation stage.
Odour control	The contained nature of the system should allow the containment of any odours. In some systems considerable quantities of air are used and this can result in the need for very large, sophisticated, and expensive wet scrubbers and biofilters to remove odour from the air.
Bioaerosol control	The contained nature of the system allows the containment of bioaerosol-carrying air.
Data recording and analysis	There are normally excellent facilities for the recording and analysis of process parameters.
Manpower requirements and potential for automation	A high degree of automation is possible with continuous systems.
Time required for composting	The duration of composting depends upon the feedstock used and the potential use of the finished compost. The residence time within the various systems varies from 7 – 60 days. This is often followed by a period of further composting or maturation.
Siting of facility	The contained nature of the process can reduce the effect upon the local environment and hence modify siting requirements. However, there is often the potential for odour generation by the feedstock, the early stages of the process, and the air treatment system.
Capital cost	These are normally very capital-intensive systems.
Processing cost	The processing cost varies considerably with the size of the facility and the efficiency with which it is run. Because of the large quantities of material that can be processed in a continuous system there is the potential to operate these systems at a relatively low process cost per tonne.
Area requirements	Vertical flow systems normally have a smaller land requirement than open composting systems.
Product quality	Product quality varies considerably.

9.4 Horizontal or inclined flow continuous composting systems [Type II B]

9.4.1 Schematic of horizontal/inclined systems

A schematic for a typical horizontal flow system is shown in Figure 9-3. Not all systems have all of the attributes shown. Material enters the system on a continuous or intermittent basis, travels along the length of the system and leaves the other end, again on a continuous or intermittent basis.

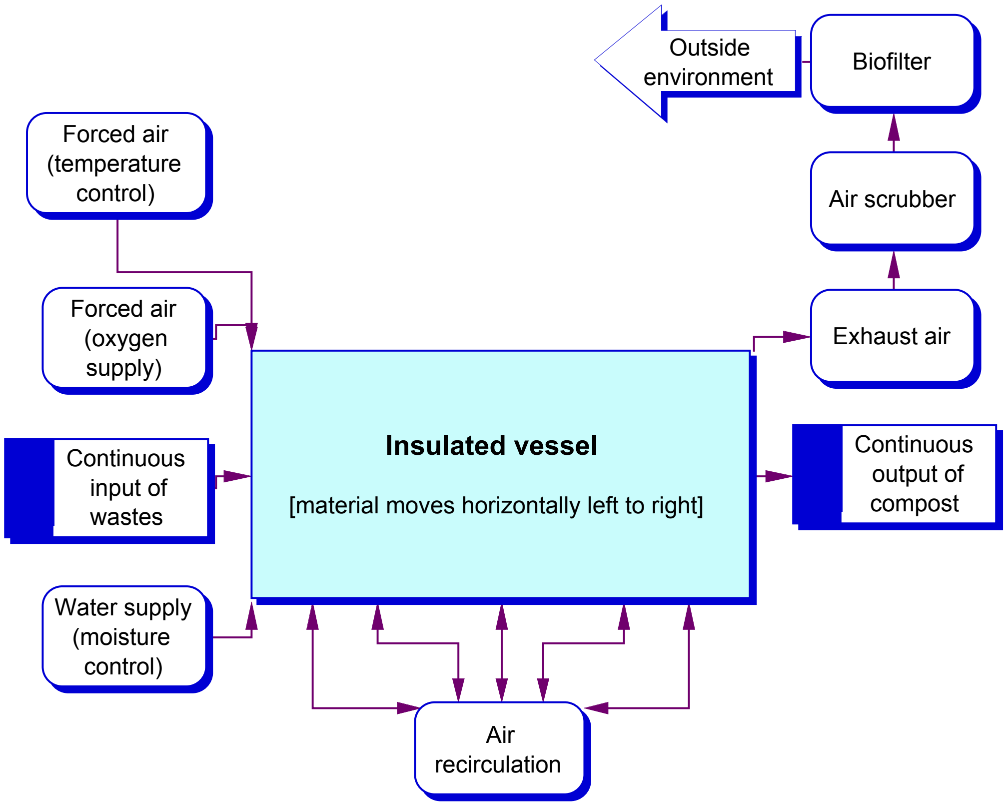

Figure 9-3: Typical horizontal flow system

Horizontal or inclined contained systems can be divided into several types, according to the structure of the container and the way in which the composting waste is moved or agitated.

Rotary (rotating) drums [Type II B i]
In the commonest form of this technology feedstock enters at one end of a large, inclined rotating drum and gradually moves along the drum to exit at the opposite end (Figure 9-4). There are several variations of the drum system, including one in which the drums are divided into three or more cells. The content of each cell is emptied into the next cell in turn, preventing any of the feedstock from short-circuiting the process. This also allows an intermittent delivery of feedstock into the drum, one cell at a time, rather than a continuous delivery. Material takes in the order of three days to pass through the drum. During this time, temperatures increase and the structure of the material changes considerably (Anon 1995). However, composting is in no way complete, and an extensive windrow or aerated static pile composting stage must follow.

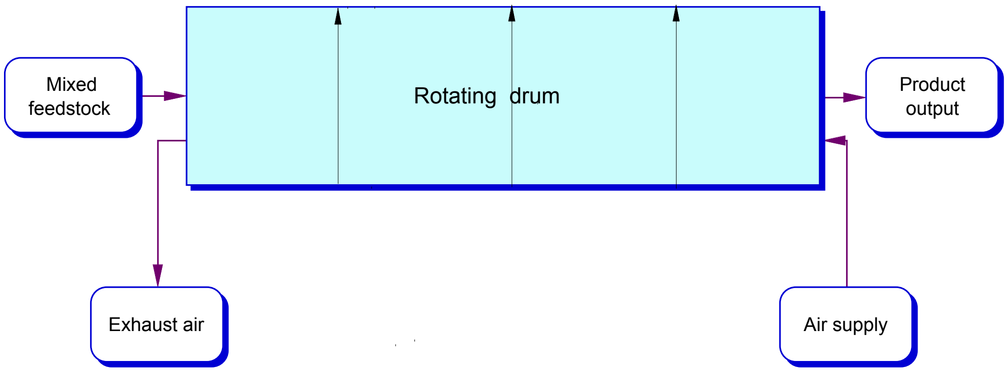

Figure 9-4: Rotating drum reactor

This windrow or aerated static pile can cause odour problems. Air should be extracted from the process and passed through a scrubber and biofilter.

Agitated bins – circular [Type II B ii a]
In the circular agitated bin method, feedstock is fed into the bin at one edge on a continuous basis (Figure 9-5). A mixing device, such as a set of augers, is then slowly rotated around the bin. This action agitates and mixes the composting waste and slowly moves it towards the centre of the bin where it exists and is removed by a conveyor. The reverse path may also be used. Air may be forced through the composting waste to control temperature and maintain adequate levels of oxygen.

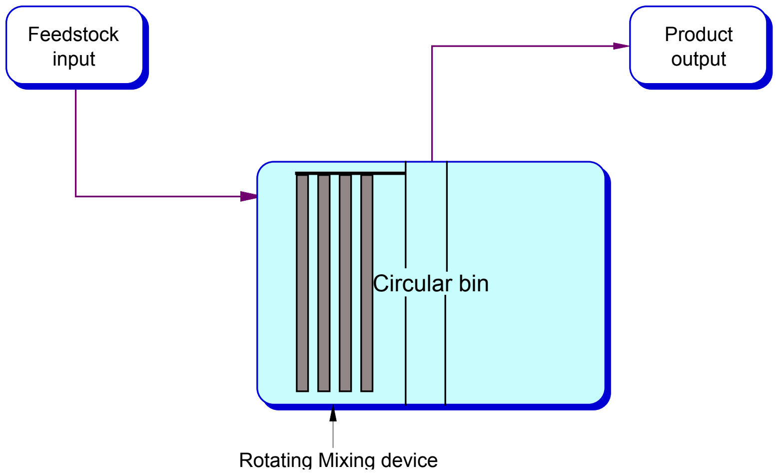

Figure 9-5: Circular bin reactor (side view)

Air leaving the system, and any odour-carrying air from the building in which it is situated should be extracted and passed through a scrubber and biofilter.

Agitataed bins (bays) – rectangular [Type II B ii b]
Rectangular-shaped, open-topped, agitated bays are available in a wide variety of forms, from the nearly square to very elongated rectangles (Figure 9-6). These systems normally operate on a continuous or intermittent feed basis, with feedstock entering one end of the bay, being slowly moved along the bay by some mechanism, and leaving the other end of the bay some 14 days later, again on a continuous or intermittent basis, (Kugler and Leisner 1996, Carr et al. 1998, Day et al. 1998, Block 2000, Goldstein 2000). The bays are often constructed from concrete and take the form of 2-3 metre high vertical walls 2-6 metres wide and up to 200 metres long.

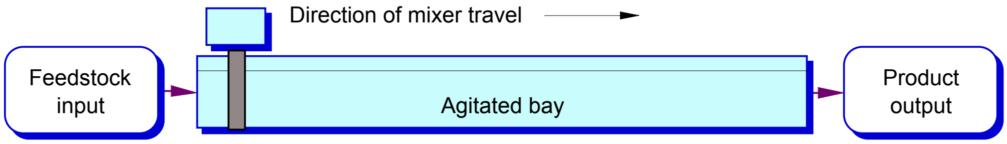

Figure 9-6: Rectangular agitated bay (side view)

Agitation of the composting waste is accomplished in a number of ways, normally by means of an agitator mounted on rails on top of the walls. As the agitator (turner) moves through the composting waste it gradually moves it along the bay (Figure 9-7). Aeration and a degree of temperature control are provided by air blowing through holes in the floor of the bay.

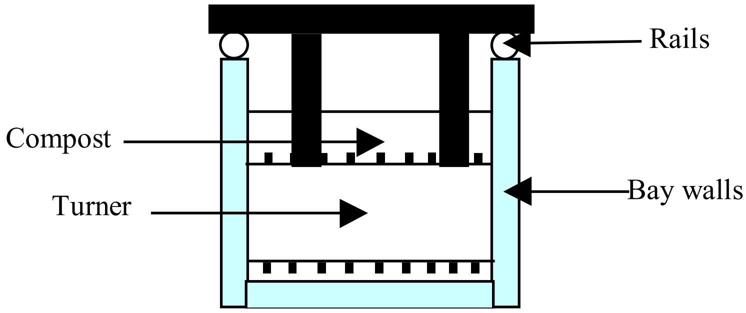

Figure 9-7: Rectangular agitated bay (end view)

As these systems are normally constructed within a building, odour-carrying air, sometimes very large quantities, has to be extracted and passed through a scrubber and a biofilter.

Continuous tunnels – plug flow [Type II B iii]
These are concrete or steel structures that are square or rectangular in cross section (Figure 9-8) (Anon 1995a). The dimensions can vary considerably giving a capacity of 10 to 200 tonnes or more.

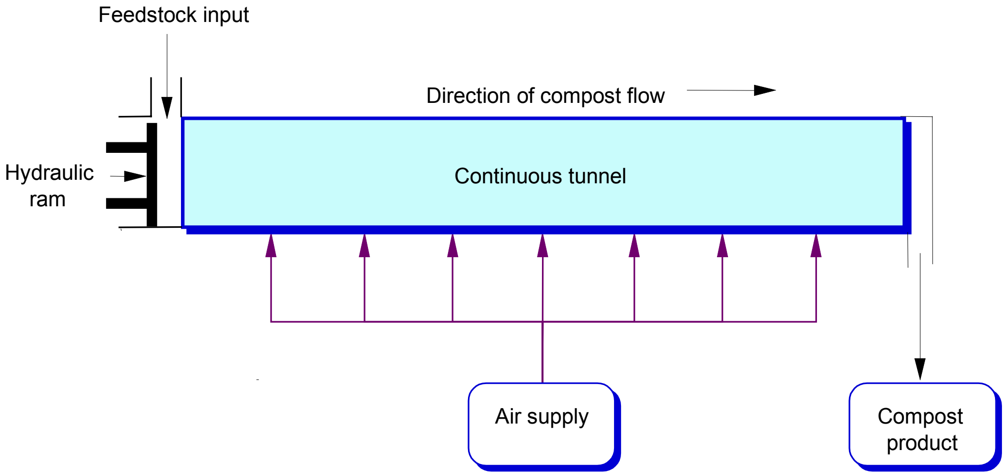

Figure 9-8: Continuous tunnel - plug flow (side view)

At one end of the tunnel, a vertical metal plate (ram) is positioned to act as a closure. This is hydraulically powered to move away from the end of the tunnel as required, creating a space the height and breadth of the tunnel and about 1 metre deep. Suitably prepared feedstock is fed into the top of this space by a conveyor until the void is full. The hydraulic ram then closes, forcing the feedstock into the tunnel and closing that end of the tunnel again. At the same time, all of the material in the tunnel is pushed the sam towards the opposite end where finished product is dropped off onto a conveyor and removed for further treatment. Some compression of the material takes place as it moves along the tunnel. This filling process is continued on a daily or more frequent basis.

Aeration is supplied by means of fans linked to the perforated floor of the tunnel. Typically, the tunnel floor is divided into several regions, each with an independent air supply. This enables the composting waste to be taken through a number of different composting stages (warm up, pasteurisation, conditioning, cool down) as it travels along the length of the tunnel. The supply of air is normally a single pass system, that is, there is no recycling of the air as seen in some batch tunnels (see below). Air leaving the tunnels carrying odours should be passed through a scrubber and biofilter. Quite large volumes of air have to be treated.
The residence time in the tunnel is in the order of 14 days.

Continuous tunnels – walking floor [Type II B iii]
This system operates as above, but with a walking floor rather than a hydraulic ram used to move the composting waste along the tunnel rather than a hydraulic ram (Figure 9-9).

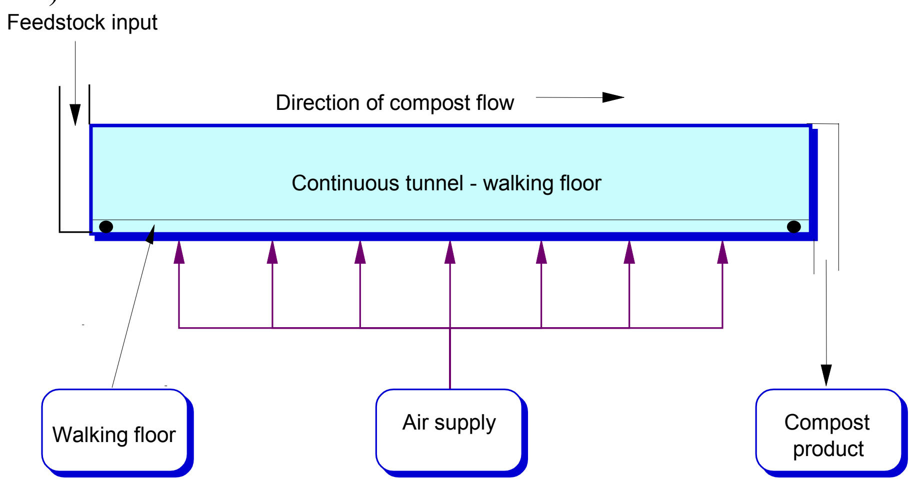

Figure 9-9: Continuous tunnel - walking floor (side view)

Odour-carrying air should be treated in the same way as with the hydraulic ram continuous tunnel.

9.4.2 Strength and weaknesses of horizontal flow composting

The strengths and weaknesses of horizontal flow composting are summarised in Table 9-2. As there is considerable variation between the many different types of horizontal flow composting systems some of the comments may not apply to all systems.

Table 9-2: Strength and weaknesses of horizontal flow composting

Feature	Comments
Temperature control	The common use of agitation and forced aeration, and the containment of the composting process, provide the potential for a much higher degree of temperature control than with open systems. In some systems there is often the ability to take the composting waste through a pre-determined temperature regime and to carry out the process at nearer optimal conditions. In simpler systems, such in agitated bay composting, this ability is more limited.
Aeration control	The efficiency of aeration possible in the various forms of horizontal flow varies considerably. However, the potential exists for a great improvement over open composting systems.
Moisture control	There is often the facility to control moisture during the composting process by the addition, or recirculation, of water at different stages.
Particle size control	The initial reduction in particle size is accomplished by shredding. The movement of the material through the composting system may also result in further particle size reduction.
Structure control	The continuous movement of material through the system can result in the reformation of air spaces. In some cases, such as the plug-flow system, the composting waste can become compressed during processing.
Homogeneity	If the feedstock mixture is kept uniform, the horizontal flow system can produce a homogenous end product. The rotating drum system is particularly efficient at homogenising mixed wastes such as MSW prior to further composting.
Pasteurisation	Some systems can take waste through a very effective pasteurisation stage.
Odour control	The contained nature of most horizontal flow systems allows the control of any odour-carrying process air. In some systems considerable quantities of air are used in the processing and this can result in the need for very large, sophisticated, and expensive wet scrubbers and biofilters to remove odour from the air. Some horizontal flow systems, such as the agitated bay system, are not fully enclosed, and are operated within a building. In this case, air from the building as a whole has to be processed to avoid the release of odours.
Bioaerosol control	The contained nature of some systems allows the full containment of bioaerosol-carrying air. In systems such as agitated bays, additional steps for aerosol containment are necessary.
Data recording and analysis	There are normally excellent facilities for the recording and analysis of process parameters.
Manpower requirements and potential for automation	A high degree of automation is possible.
Time required for composting	The duration of composting depends upon the feedstock used and the potential use of the finished compost. The residence time within the various systems varies from 3-21 days. This is normally followed by a period of further composting or maturation.
Siting of facility	The contained nature of the process can reduce the effect upon the local environment and hence modify siting requirements. However, there is often the potential for odour generation by the feedstock, the early stages of the process, and the air treatment system.
Capital cost	These are normally very capital-intensive systems.
Processing cost	Because of the large quantities of material that can be processed in a continuous system, there is the potential to operate these systems at a relatively low process cost per tonne.
Area requirements	Horizontal flow systems normally have a smaller land requirement than open composting systems.
Product quality	Product quality can be very high.

9.5 Batch composting systems [Type II C]

9.5.1 Schematic of batch systems

A schematic for a typical batch system is shown below. Some systems do not recirculate the air. A number of articles have been written on batch tunnel composting (Lokin and Oorthuys 1994, Boody 1996, Panter et al. 1996, Grabber et al. 1997, Chalmers and Donahue 1998, Donahue et al. 1998).

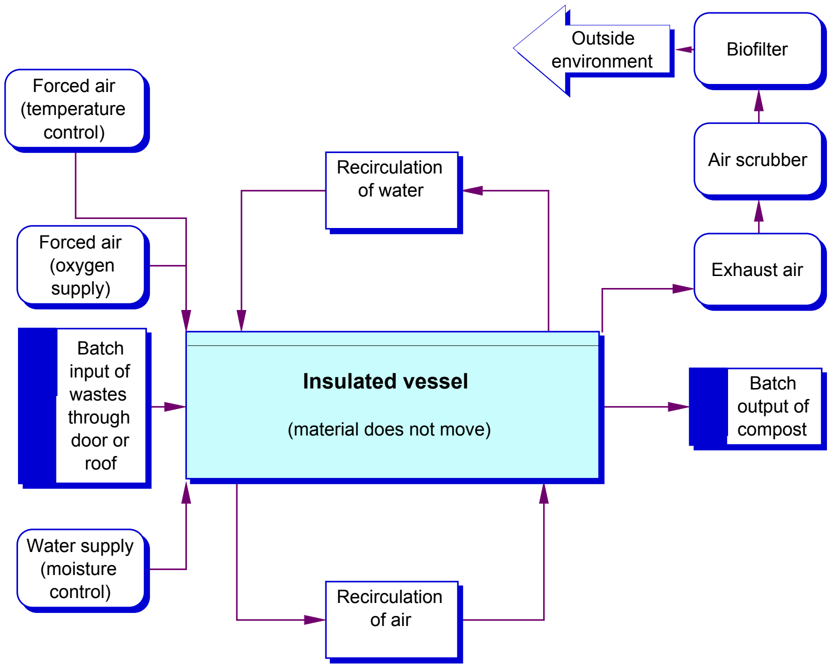

Figure 9-10: Batch tunnel system

Open bays – [Type II C i]

In this type of batch system the composting waste is held between concrete walls usually about 3 metres high, 3 – 5 metres apart and up to 25 metres long. The floor of the bay is perforated and connected to a fan to supply forced air. There is no roof to the bay and there are no end walls, or a wall only at one end. The bay is filled to a depth of about 2 metres. Air is then forced through the composting waste without any recirculation. Temperature and oxygen probes in the compost, linked to a computer, are commonly used to control the process. Air supply may be continuous or pulsed. The composting waste may be removed from the bay, mixed, and re-filled part of the way through the process. This system has been successfully use in recent years in the UK mushroom composting industry as a cost effective replacement for open windrows.

Fixed batch tunnels – [Type II C ii]

This system uses a closed concrete or steel box to contain the composting waste. Dimensions vary from 3 - 5 metres high, 3 - 5 metres wide and up to 25 metres or more in length. Tunnel capacity can vary from 10- 200 tonnes (equivalent to 250-5000 tonnes per year). The walls and top of the tunnels are normally insulated. In some systems, there is a removable door at one end to allow filling and emptying, while in others there are doors at both ends, allowing filling to take place at one end and emptying at the other end. This can have advantages in keeping finished product separate from unprocessed material. The tunnels are filled by front-end loader or conveyor to a depth of about 2 metres, the exact depth depending upon the bulk density and porosity of the mixture. A gap, or headspace, of about 1 metre or less is left between the top of the compost and the roof of the tunnel to aid circulation of air. Once the tunnel is filled it the doors are sealed; any air leaving the exhaust port of the tunnel is taken directly by ducting to a wet scrubber and biofilter.

The floor of the tunnel is made from concrete or steel, perforated with holes about 1 cm. in diameter, or constructed from slats of concrete with spaces between the slats. The floor is sometimes fitted with a plenum, or space, underneath it. Air is blown by a fan through the floor structure, through the composting waste and recirculated to the fan through ducting. Temperature is controlled by allowing fresh air to enter from outside the tunnel through a motorised variable flap. The ratio of fresh to recirculated air determine minimum oxygen levels within the compost and also controls the temperature throughout the compost. The entire composting mass is at almost the same temperature at any one time. The whole system is normally computer controlled allowing full monitoring, recording and analysis of data. The residence time for the compost is in the order of 14 days.

Because the internal environment of the tunnel is so tightly controlled, composting proceeds at near optimum conditions and is therefore very rapid. The composting waste can be taken through a pre-determined and tightly specified composting regime.

The finished compost is removed by a front-end loader or an automatic emptying device and either screened immediately or left to mature for a period of weeks. In some operations the compost is removed after one week, screened to remove oversized particles, and refilled into a second tunnel for a further week's composting. These batch tunnels have been used for many years in the UK to produce the high specification compost required for the commercial growing of white mushroom.

Mobile batch tunnels – [Type II C iii]
Mobile batch tunnels (mobile batch containers) can either be smaller versions of the fixed batch tunnels described above or they can be systems that use single-pass air without recirculation to control temperatures. They may be based upon commercially available roll-on, roll-off containers. They are normally transported by roll-on, roll-of lorries or by flat-bed trucks. They are all controlled to varying degrees by a computer that measures and controls oxygen levels and temperatures.

Mobile batch tunnels are flexible in their use. The container may be taken to the waste and compost this in situ, or the container is used to collect the waste and to transport it to a centralised composting facility where a large number of containers me be operated at the same time. Alternatively, the waste can be taken to the container at a composting facility.

Filling can be by a front-end loader through a moveable roof to the container, or through an end door by means of a front-end loader or a conveyor. Emptying can be by a front-end loader through an end door, by means of a winch attached to a woven plastic sheet underneath the compost pulling the compost through an end door, or by tipping the container.

9.5.2 Strengths and weaknesses of batch composting

The strengths and weaknesses of batch composting systems are summarised in Table 9.3. The different types of batch composting systems tend to vary much less in structure and operation than vertical and horizontal flow systems.

Table 9:3: Strengths and weaknesses of batch composting

Feature	Comments
Temperature control	In systems that use a continuous supply of recirculated air there is an excellent level of temperature control, both in terms of the temperature itself and in the uniformity of temperature throughout the composting waste at any one time. In systems that use pulsed aeration, or single pass aeration, i.e. no recirculation of air, temperature control is less well controlled but is still much better than in other non-batch systems. In open bay batch systems there is a lesser degree of temperature control
Aeration control	Aeration of batch systems with a continuous supply of recirculated air provides excellent aeration with the ability to ensure that oxygen levels at any point in the system do not fall below a predetermined level. Batch systems with a pulsed supply can also be very effective.
Moisture control	Some systems have the ability to recirculate water that condenses or drains to the base of the composting container.
Particle size control	The initial required reduction in particle size is accomplished by shredding. In some operations, there is no movement of the material during composting. In these cases, the particle size has to be correct at the time of filling. In other operations, the material is removed from the composting container after a period of time. It can then be shredded again, and/or screened, before being returned to the container for further composting..
Structure control	The structure of the composting waste has to be correct at the time of filling. In some systems (see particle size control ?) the material is removed from the container at some point and the structure of the material can be modified if necessary before composting is continued.
Homogeneity	It is essential that the material is homogeneous before being filled into the container. Once in the container, the uniform process conditions will maintain this homogeneity.
Pasteurisation	In systems that use a continuous supply of recirculated air it is possible to guarantee uniform pasteurisation conditions for a pre-determined period of time.
Odour control	The fully contained nature of most batch systems allows the total containment of odour-carrying air enabling its effective treatment with a wet scrubber and biofilter.
Bioaerosol control	The fully contained nature of the batch systems allows the total containment of bioaerosol-containing air enabling its subsequent treatment to remove bioaerosols.
Data recording and analysis	There are normally excellent facilities for the recording and analysis of process parameters.
Manpower requirements and potential for automation	High degree of automation is possible.
Time required for composting	The duration of composting depends upon the feedstock used and the potential use of the finished compost. The residence time within the various systems varies from 7-14 days. This is often followed by a period of further composting or maturation, depending upon the eventual use of the compost.
Siting of facility	The contained nature of the process can reduce the effect upon the local environment and hence modify siting requirements. However, there is still the potential for odour generation by the feedstock before it is filled into the container.
Capital cost	These are normally fairly capital-intensive systems.

Feature	Comments
Processing cost	The processing cost varies considerably with the size of the facility and the efficiency with which it is run. Because of the modular nature of the batch system, it is normally possible to ensure that the facility operates at near optimum capacity.
Area requirements	Batch systems require a relatively small footprint..
Product quality	Product quality is normally very high compared to most other composting systems.

10. COMMERCIAL CONTAINED COMPOSTING SYSTEMS

10.1 Continuous vertical flow systems

There are many different forms of continuous vertical flow systems available.

10.1.1 American Bio Tech (USA)

This is a modular vertical flow system in which suitably shredded and mixed feedstock is fed in to the top of 8 metre high cuboid containers (Figure 10.1). The material moves down the container by gravity into the void left by finished compost being removed. This is taken from the bottom of the container by a horizontal auger that feeds a conveyor, again on a daily basis. The residence time in the container is typically 21-60 days.

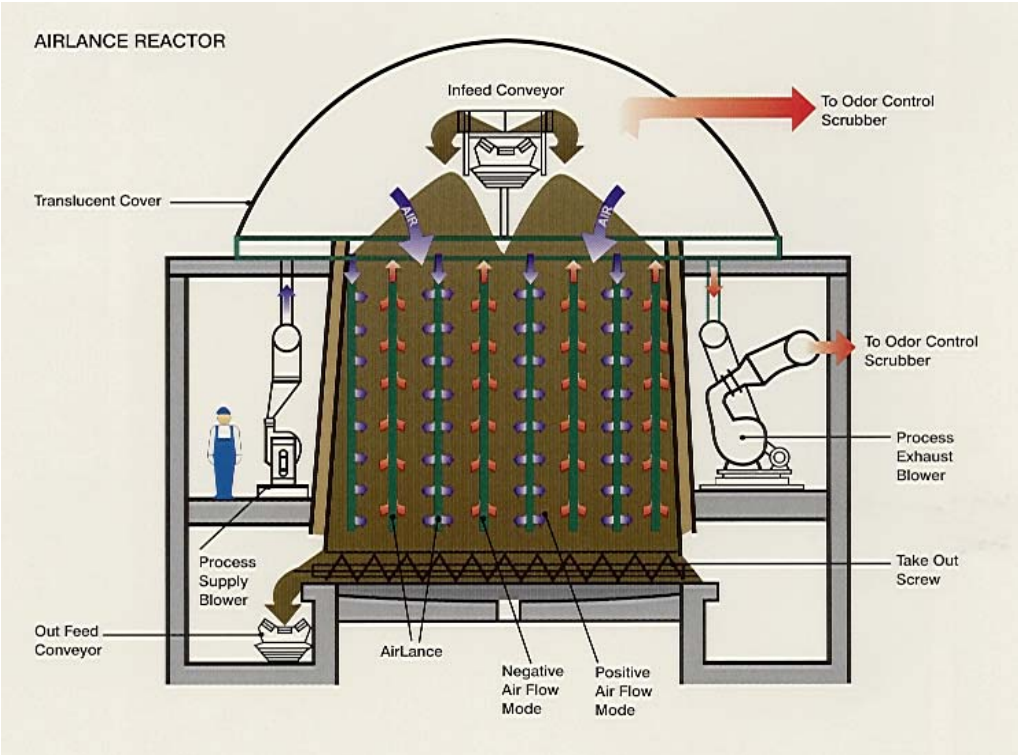

Figure 10-1: American Biotech AirLance composting system

Each container is fitted with a set of vertical air lances that penetrate to the bottom of the compost (next Figure). These can be operated, under computer control, to either blow or suck air through the compost. Because of the short horizontal distances between the lances, it is claimed that there is very little opportunity for anaerobic conditions to occur. A heat exchanger is used to cool odour-carrying exhaust air before it is passed through a biofilter for odour removal.

Figure 10-2: American Bio Tech - air lances providing lateral movement of air

The number of containers used will depend upon the total capacity of the facility. A facility set up to process 700 t/day of waste (400 t/day of sewage sludge mixed with 300 y/day of shredded wood waste) occupies an area approximately 35 metres by 150 metres.

Typical site:
Schenectady, New York:

10.1.2 Weiss Bio Anlagen GmbH (Germany)

The entire Weiss process, from the delivery of the feedstock (biosolids or MSW) to the removal of the compost, is operated within a closed environment (next Figure).

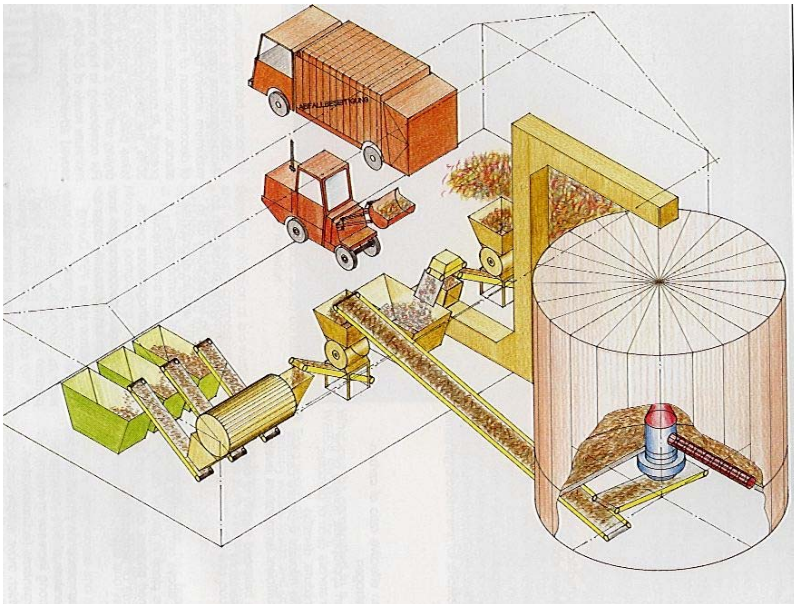

Figure 10-3: Weiss Bio-Reactor - schematic

After passing through a magnetic separator, shredded and mixed waste is transported via a conveyor to the top of the composting tower where it is distributed evenly. The tower is filled in this manner and processing begins. Air is blown into the composting waste, from the bottom of the tower to the top, alternately through four floor segments. Air leaving the tower is either redirected through the compost or is passed through a biofilter to remove odours.

The oldest material, at the bottom of the tower, is removed by automatic conveyor (next Figure) and taken through a trommel screen to produce a compost product and an oversize fraction. This leaves a space at the top of the tower into which fresh feedstock can be filled. The entire process is computer-controlled with the composting tower and all of the conveyors and other equipment inter-linked. The temperature of the composting waste is measured at several points down the tower, and the oxygen concentration in the processing air is continually monitored.

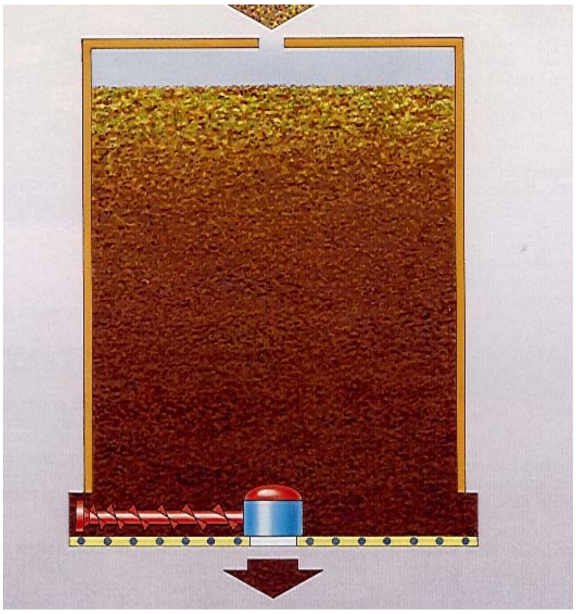

Figure 10-4: Weiss Bio-Reactor – vertical section showing emptying auger

The composted material is removed after screening and matured for a further six weeks.

Typical sites:
Bozen, Italy: 100,000 tpa municipal waste, 1991
St. Leonard, Uvrier, Switzerland: 3,300 tpa of sewage sludge, 1994
Lelystad, Netherlands: 3,000 tpa of sewage sludge, 1993
Niederdorla, Germany: 20,000 tpa of biowaste, 1995

10.1.3 Sevar Entsorgungsanlagen GmbH (Germany)

There are two main pre-treatment processes offered by Sevar Entsorgungsanlagen. The first, SEVAR pure, uses a raw primary, secondary, or co-settled sewage sludge cake feed of 20-30% dry solids. No bulking agent or amendment is added. The sewage sludge is passed over a drying belt to increase the dry solids of the material to about 50%. The resultant material should have an open and porous granular structure. This partially dried material is taken to the composting hall. The second pre-treatment method, SEVARhum, is normally used for digested sewage sludge cake and involves the additional of a higher carbon amendment such as green waste, source separated MSW, straw or sawdust. The two materials are mixed together to provide the required carbon: nitrogen ratio, moisture and structure. After mixing has taken place the material is transported to the composting facility.

Composting takes place in a two-stage tower unit. The tower is divided horizontally into two zones by a false floor constructed from pin rollers. Material enters at the top of the unit and moves down to the bottom during compost where it is removed by a conveyor. Extracted air from the composting tower in the rest of the building can be extracted and processed through a biofilter.

10.1.4 TEG Environmental (UK)

The TEG Silo-Cage system (next Figure) is a recent system that is considerably different in concept from other systems described (Bilborough 1998). It is fashioned from a wire mesh cage divided vertically into 7 or more independent cells. These cells are not insulated.

Figure 10-5: TEG composting cage

Shredded and mixed feedstock is fed onto an elevator that takes it to a loading head that rides along the top of the cage, delivering feedstock to the appropriate cell. At the bottom of the cage is an extraction auger (Figure 10.6) that runs the length of the cage and removes composted material from the bottom of each cell. It is intended that the material is composted in the time that it takes to travel from the top to the bottom of the cell. The typical residence time is said to be 6-21 days. This can then be followed by a secondary maturation stage outside the cage if required.

Figure 10-6: TEG extraction auger

10.2 Continuous horizontal or inclined flow systems

There is a wide variety of this type of technology available.

10.2.1 Bedminster Bioconversion Corporation (USA) – Rotary Drum

This system (Figure 10-7) can be used to compost a wide variety of wastes, including MSW, biosolids, food processing wastes, and farm wastes, (Goldstein 1996). In the case of MSW hazardous, oversized, and unacceptable items such as pallets, carpets, wire, garden hose, appliances, large metal containers, drums and car batteries are removed prior to processing. The remaining material is filled into the composting system by a hydraulic feed. Sewage sludge, manures, grease trap waste, and septic tank contents can be collected separately and can then be added to the MSW component.

Figure 10-7: Bedminster composting plant at Cobb County USA

The Bedminster system consists of a computer-controlled, rotating drum or 'Digester' (Figure 10-8) that is divided into three chambers, each providing a different composting environment.

Figure 10-8: Bedminster composting system – rotating drums

Each day, the last chamber is emptied, material in chamber 2 is moved into chamber 3 and the material in chamber 1 is moved into chamber 2. The now empty chamber 1 can then be filled with fresh feedstock. The total residence time in the drums is therefore 3 days. Temperature, moisture, and oxygen levels can be monitored and controlled in each chamber. Temperatures between 55-65°C are achieved. The capacity of a drum can range from 5-100 tonnes per day of MSW. The number of drums in a facility can be increased to allow for expansion.

The material passing through the drum is reduced in size and homogenised during the three days of processing. This comminution and homogenisation aids the subsequent separation of inert materials and the final composting stage. After leaving the third chamber, the material is screened. Oversized material is separated for recycling or landfilling. Ferrous materials are removed magnetically, and aluminium is separated by an eddy current separator. Plastics can be recovered through a screening process. The system differs from many other methods in that there is no shredding or grinding of the feedstock prior to processing and is therefore well adapted to the use of unsorted MSW feedstock.

The remaining organic material is then piled up on a perforated concrete pad, and air is blown through it to supply oxygen and to control temperature. The pre-treatment of the organic material in the drum helps rapidly to establish an effective biodegradation process. The process can be carried out within a building so that extracted air can be passed through a biofilter to remove odours. The material is periodically turned over a period of 4-6 weeks. It is then screened again to produce a compost type product and an oversized component. The final compost product is used immediately, or left to mature, depending upon its eventual application. The Bedminster compost type product has been tested under the US Environment Agency (EPA) 503 regulations and has been designated Class A. Air leaving the plant is taken through a soil biofilter to remove odours and VOCs.

The volume of compost produced by the co-composting of MSW and sewage sludge, in a ratio of 2:1 by weight, is about one third of the input volume. The compacted volume of the non-degradable residue from the process is about 20% of the input volume. In terms of weight, a fill of 150 tonnes of MSW and sewage sludge (2:1) will result in about 30 tonnes of mainly non-organic residue being sent to landfill after processing.

10.2.2 Motherwell Bridge Environmental Ltd (UK) – Rotary Drum

This technology (Figure 10-9) was originally designed by the Dano Company in Denmark (1935) and was used in some 100 composting facilities up to the early 1970s. The operation was transferred to Switzerland in 1972 where it operated through a network of licensees operating in specific territories. The Dano Company was bought by the Motherwell Bridge Group at the end of the 1980s. The company remains based in Switzerland but is controlled from the UK. The manufacturers state that over 175 composting plants have been set up using this technology.

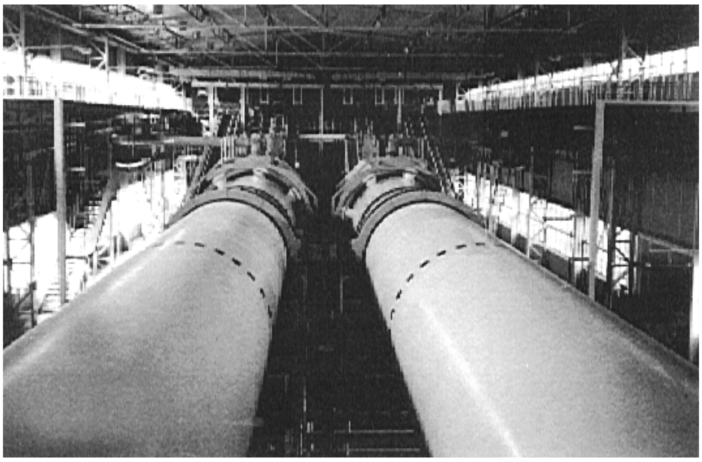

Figure 10-9: Two rotating Dano drums

In the Dano system, mixed waste is fed continuously into one end of a large rotating drum, with water being added if necessary. The drum rotates at 3.5 rpm and this rotating action, aided by the presence of hard objects such as stones and metals in the waste, produces a pulverising effect. The drums are typically 24 metres long and 3.8 metres in diameter. The drum conditions the organic fraction of mixed waste or shredded green waste, over a residence time of 6 – 8 hours, by increasing its bulk density and by making it more homogenous. This enables the organic fraction to be more easily separated from inert contaminants (Pettigrew 1994, Hui and Hatton 1997). Agricultural studies have been carried out on MSW put through the Dano process followed by windrow composting, (Sela et al. 1998).

Because of the high temperatures generated within the drums, some initial breakdown of the organic fraction occurs along with some degree of pathogen kill. Moisture can be controlled within the drums by the addition of water or of dry waste (paper) and the compost typically leaves the drums at 55 - 60% moisture. An integral screen in fitted at the discharge end of the drum and this is used to produce two fractions. One fraction consists mainly of the organics which are now of small particle size and suitable for further treatment. The other, oversized fraction is high in plastics and can be incinerated or used in the preparation of refuse-derived fuel. The typical throughput of a drum is 18 – 20 tonnes/hr of mixed refuse, equating to a throughput of about 40,000 tpa on a single shift operation. The drum treatment is normally followed by a turned windrow or aerated static pile composting stage. This stage may be carried out in the open or within a building depending upon local sensitivities. If carried out within a building it should be possible to extract any odour-carrying air and process it through a biofilter.

The capital and production costs of the Dano system are site specific, a situation that applies to most of the biodegradation technologies considered in this report.

The Dano system is also used for a number of other treatment functions:

Pre-treatment for landfill - Here the drums are used to pulverise and homogenise an incoming mixed waste stream to increase its density and to more easily separate the organic and inert fractions. This facilitates the extraction of ferrous and non-ferrous wastes.

Pre-treatment for anaerobic digestion - The pre-treatment of the organic component prior to anaerobic digestion is said to enhance gas quality and yield.
Bio-remediation of oil-contaminated soils - This application is at a trial stage.

10.2.3 Fairfield Engineering Co. (USA) – Agitated bin (circular)
The Fairfield Digester is a continuous system based on enclosed circular vessels (Figure 10-10). Solid wastes, primarily biosolids, mixed with woodchips or shredded tree trimmings, are transported by conveyor to the top centre of a digester and then towards the outer edge by means of a rotating bridge. Rotating augers, attached to the bridge, gradually move the introduced material down to the bottom of the digester and towards the centre. A conveyor then removes the composted material providing space for additional fresh feedstock to be introduced. Forced air is supplied by fans to keep the composting waste aerobic and to provide a degree of temperature control. The rate of rotation of the bridge, the amount of air introduced into the digester, and the speed of the augurs are automatically adjusted to provide the optimum temperature for composting and the required retention time. The final compost product can be pelletised if required.

The front-end system can also contain a picking area to allow manual removal of unwanted material, a hammer mill to comminute the waste, a classifier to remove metal, glass, plastics and rags and a pulper to reduce the particle size still further and to adjust the moisture. A combination of sewage sludge and MSW is often used as a suitable feedstock.

Figure 10-10: Fairfield Engineering circular Digesters

The system is sealed and any odour-carrying air can be extracted and passed through a biofilter.

Typical sites:
Delaware Reclamation Product, Delaware, USA: Composting of 85,000 tpa of MSW and 90,000 tpa of sewage sludge.
Clinton County, New York, USA: Composting of 44,000 tpa of sewage sludge and 10,000 tpa of wood chips.

10.2.4 Longwood Manufacturing Corporation (USA) – Agitated bin (rectangular)

The Longwood company states that it has been involved in the manufacture of composting equipment since 1972, initially in the mushroom industry. The company entered the waste composting industry in 1986.

This agitated bay system consists of a series of concrete bays, each 2.85 m wide constructed from walls 0.254 m thick and 2.21 m high, positioned within a building (Figure 10-11). Metal rails run along the tops of the walls to enable electrically powered compost turners to ride along the full length of the bays. The quantity of waste to be composted will determine the number and length of the bays required.

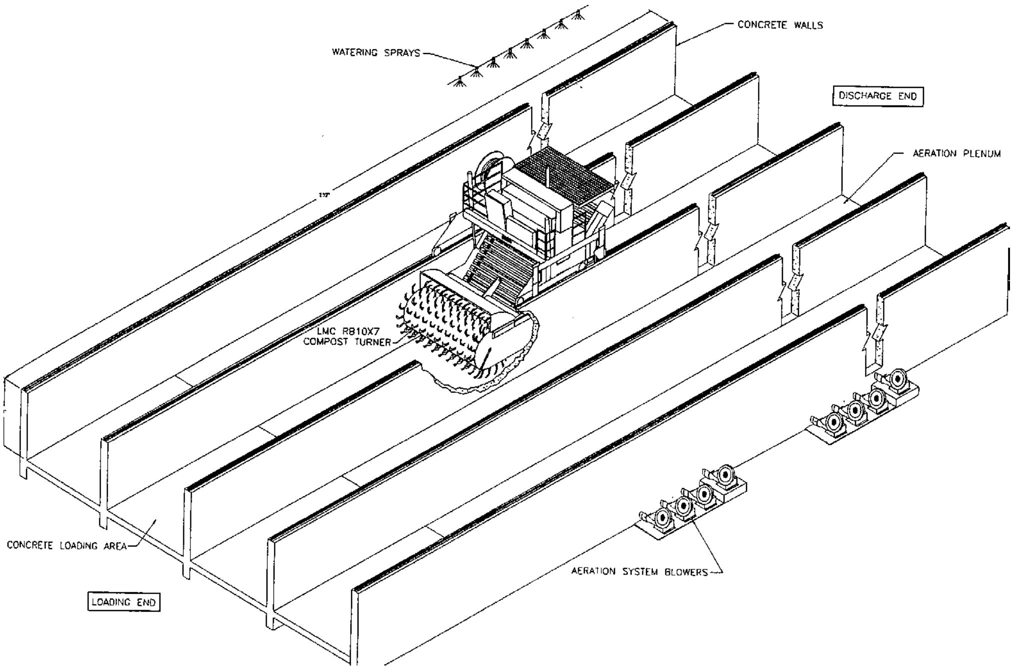

Figure 10-11: Longwood Manufacturing agitated bay system

A typical bay is 64 metres long for a five-days/week operation or 77 metres long for a six-days/week operation. Each version of the bay is divided into four aeration zones along its length, with each zone having a dedicated blower (fan). Each blower has the same capacity but the length of bay that each has to supply is shorter at the feed end. This is to allow for the greater aeration needs at the earlier stages of the composting process. The aeration system consists of perforated PVC piping, embedded in crushed stone, that runs along the length of the bay to provide aeration across the entire width and length of each aeration zone. Each aeration zone is monitored by a temperature probe. Temperatures do not exceed 55°C at any time. Water can be sprayed on to the composting waste as required.

The operator feeds in fresh feedstock at one end of the bay on a daily basis. The turner, containing a rotating drum bearing many angled spikes, travels along the length of the bay (Figure 10-12). This mixes the composting waste and gradually moves it along the bay at 4 - 5 metres per pass. The turner can be transfered laterally from one bay to another as required through a system of cross rails. This movement of the turners is under computer control, as are also the loading equipment, discharge conveyors and watering system.

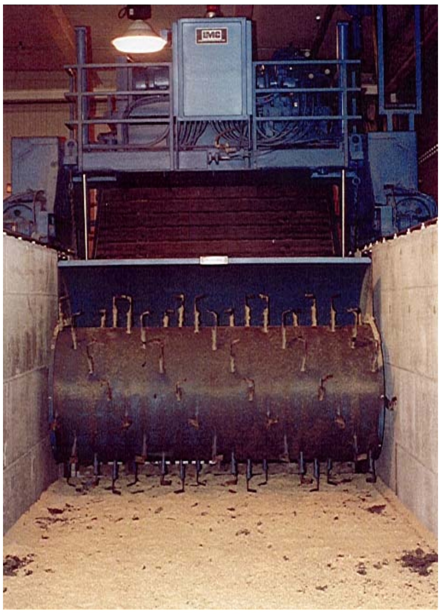

Figure 10-12: Longwood Manufacturing – agitated bay turner

The above turning system is said to be capable of processing up to 300 cubic metres of composting waste /hr. with the turner travelling at about 0.85 m/minute. The effective loading capacity is about 26 cubic metres/day/bay of a shredded mixture of bulk density between 590 - 800 kg/m^3.

The time taken for the composting process is typically in the order of 21 days. This active composting stage is normally followed by a period of several weeks maturation. The following Figure 10-13 shows the bays full of composting waste.

Figure 10-13: Longwood Manufacturing- Agitated bays filled with compost

Large volumes of odour-carrying air generated within the composting building have to be extracted by fans and passed through a biofilter.

Typical Sites:
City of Guelph, Ontario Canada: Composting of 30,000 tpa of source-separated organic waste, leaf and yard waste (garden waste), mixed with ground wood tissue. Eight bays, each 3 metres wide by 85 metres long. Three turners. Established February 1996, (Gies 1998).

St lehia, Norway: Composting of 20,000 tpa of source-separated organic waste mixed with yard waste, and Municipal Solid Waste mixed with yard waste. Nine bays, each 3 metres wide by 64 metres long. Two turners. Established April 1996.

Santa Rosa, California, USA: Composting of 35,000 tpa of sewage sludge (20,000 tpa) and yard waste (15,000 tpa). Twelve bays, each 3 metres wide by 64 metres long. Three turners. Established June 1996.

10.2.5 VAM (Netherlands) – Agitated bin (rectangular)

The VAM composting site at Wijster is the largest in the Netherlands, (Oonk and Woelders, 1999). It is used to compost 400,000 tpa of source-separated vegetable, fruit and garden organic waste. Composting has taken place at this facility, using a number of technologies, for more than 60 years. The organisation composts a total of more than 800,000 tpa of organic waste at three regional composting sites in Purmerend, Moerdijk and Rotterdam are included. This represents about 40% of all such waste collected in the Netherlands.

The organic feedstock is first taken through a rotating drum where it is screened to remove oversized material. Ferrous materials are then removed by an electromagnet. Both of these stages take place within a building. The waste is then transported by conveyor to a closed composting building. This building is divided into a number of composting sections or bays. Over a period of six weeks it is moved by a rotating compost turner (next Figure), running on rails on top of the walls of the bays, from one bay to the next. This turning action mixes the material thoroughly and allows the moisture level of the material to be controlled.

Figure 10-14: VAM composting bay with compost turner

Aeration is supplied by fans linked to perforation pipes embedded in the floor of the bays, the air first passing through a layer of gravel to ensure that it is dispensed evenly. The composting waste is kept at 55°C during the six-week composting period by the automated process control system. This system uses temperature, moisture and oxygen levels to control the process. After six weeks, the compost is transferred to the post-composting area where it is screened into a number of different sized fractions. The screened compost is then matured for several months.

The composting building is sealed to avoid the release of odours. Odour-carrying air is removed from the building. Some of this (60%) is reused to aerate the compost, while the remaining 40% is passed through an ammonia scrubber and biofilter to remove odours before the air is released to atmosphere. Any leachate produced during composting is taken to a treatment plant.

Typical sites:
Wijster, Netherlands: 400, 000 tpa organic waste

10.2.6 Plus Grow Environmental Ltd. (UK) – Agitated bin (rectangular)

The Plus Grow Bay Composting system consists of a series of parallel concrete walled bays that are 2.5 metres wide, 2.75 metres high and 70 metres long. Shredded and mixed organic feedstock is fed into one end of a bay to a depth of about 2 metres. A diesel powered, hydraulically-driven turner runs along rails on top of the walls and is used to turn the compost at intervals. As the material is turned it is gradually moved along the length of the bay at a rate of 5 metres every second day. It therefore takes approximately 28 days for material to move the full length of the bay. The turner machine can be transferred from one bay to the next as required. The annual throughput for a 6 bay system is said to be 17-20,000 tpa. If required, the system can be contained within a building.

Typical sites:
Blackpool, UK. 2 bay system. 8-10,000 tpa of green waste, segregated food waste, and stable bedding.

10.2.7 BOL (Germany) – Agitated bin (rectangular)

The BOL composting plant is enclosed within a building divided into a waste reception area and composting area. The capacity of a single unit can vary from 9,000 to 20,000 tpa of organic waste. Shredded and mixed organic waste is fed into the composting bays by a crane transport mixing head after moisture has been adjusted.

The computer controlled mixing head is used to receive and transport the feedstock, fill the composting bays, mix and move the compost, and to empty the bays once composting is completed. The head is also used to shred the feedstock at the start of the process, removing the need for a separate shredding process. Air is supplied to the process by fans connected to the perforated floor of the bays. The aeration system is used to supply oxygen and control temperature. Heat exchangers can be fitted to utilise some of the heat generated by the composting process and warm the air some of which can be recycled back through the composting process. Air leaving the composting area is taken through an ammonia scrubber and biofilter system. Any leachate generated can be stored in tanks and recycled through the mixer head to adjust the moisture of the composting waste.

10.2.8 U.S. Filter Corporation (USA) – Agitated bin (rectangular)

The company supplies the IPS agitated bay method of composting (Gies 1994, Byers 1995, Day et al. 1998), with over 30 facilities world wide processing about 500,000 tpa of various organic wastes. The inputs of the facilities vary from 10– 350 tonnes a day. The entire composting system is housed within a building (Figure 10-15).

Figure 10-15: US Filter facility processing c. 9,000 tpa of biosolids/green waste

Each bay is 60 or more metres long and 2 metres wide (next Figure). Aeration is supplied by fans operating through a perforated floor.

Figure 10-16: US Filter agitation bays

Agitation is accomplished by a turner that runs along the tops of the bays (Figure 10-17). This also moves the composting waste from one end of the bay to the other. Processing air leaves through a biofilter to remove odour. The process is controlled by a computer system that determines the mixing ratios of the feedstock, tracks movement of material, and regulates temperature.

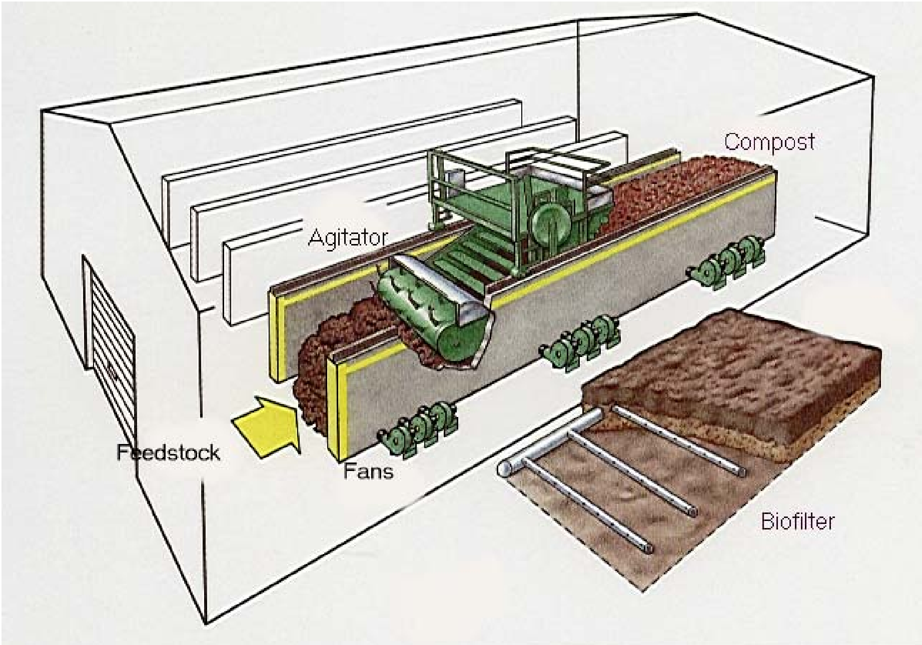

Figure 10-17: Schematic of US Filter IPS agitated bay composting

Odour-carrying process air must be extracted from the building and passed through a wet scrubber to remove ammonia and a biofilter.

Typical Sites:
Rickers Island, New York: Composting of c. 2,500 tpa of food waste and kitchen scraps. Two bays, each 64 metres long and 2 metres wide. Enclosed building 1,350 m². Biofilter 480 m^2. Established October 1996.

Baldwinsville, New York: Composting of c. 18,000 tpa of brewery residues and sawdust. Twelve bays, each 65 metres long by 2 metres wide. Enclosed composting building of 3,350 m^2, covered amendment storage 460 m^2, covered compost storage area 450 m^2, biofilter 1,500 m^2 . Established May 1989.

East Hampton, New York: Composting c. 9,000 tpa of source separated MSW, wastewater sludge and yard waste (garden waste). Six bays, each 77 metres long and 2 metres wide. Enclosed composting building 2,000 m^2 , Intermediate processing facility 4,600 m^2 . Biofilter 1,150 m^2 . Established December 1994.

Kingston, Ontario: Composting of c. 9,000 tpa of kitchen waste, food waste and yard waste. Six bays each 66 metres long and 2 metres wide. Enclosed composting building of 2,400 m^2. Biofilter 880 m^2 . Established May 1994.

Matsqui, British Columbia: Composting of c. 9,000 tpa of animal manure, food waste, paper waste and yard waste. Six bays each 67 metres long by 2 metres wide. Enclosed composting building 1,300 m^2 , covered receiving area 580 m^2 , compost storage building 1,450 m^2 , and packaging area of 740 m^2 . Biofilter 420 m^2 . Established November 1991.

Lockport, New York: Composting of c. 18,000 tpa of sewage sludge, wood chips, leaves and grass trimmings. Twelve bays, each 77 metres long and 2 metres wide. Enclosed composting building 3,900 m^2 and Covered compost storage area 465 m^2 . Biofilter 1,500 m^2 . Established March 1991.

Merrimack, New Hampshire: Composting of c. 22,000 tpa of sewage sludge, sawdust and yard waste. Fifteen bays, each 67 metres long and 2 metres wide. Enclosed composting building 3,700 m^2. Biofilter 1,400 m^2. Established October 1994.

10.2.9 Consolidated Envirowaste Industries Inc. (Canada) – Agitated bin (rectangular)

A wide variety of wastes have been processed using a basic aerated, temperature controlled, agitated bay system with a residence time of 15 –21 days. The system is set up within a building, and odour-carrying air is extracted from the building by fans and taken though an open biofilter. Finished compost product is taken to a storage building by a walking floor/conveyor system, where it is normally stored for two weeks before screening. It is then matured for a further two months.

Figure 10-18: Consolidated Envirowaste Industries – agitated bay turner

Typical site:
Abbotsford, British Columbia (only facility): Composting of 15,000 tpa of organic waste. Composting building and support areas of 12,140 m^2. Established October 1991.

10.2.10 Kruger A/S (Denmark) – Agitated bin (rectangular)

This system consists of four zones set up within a building (Nielsen 1996, Nielsen 1996a). Shredded and mixed waste enters zone 1 and is moved, by means of rotating screws, through zones 2, 3 and 4 over a 30 –35 day period. Air is supplied through the top of the system, while hot air from zones 2 and 3 is recirculated to zone 1 where it is used to warm the incoming waste. In the first part of zone 3 the temperature is allowed to rise to 70° C to bring about pasteurisation. Zone 4 is used as a biofilter to remove odours from air exiting the system. No outside biofilter is considered necessary. After composting, the finished material is screened.

Figure 10-19: Kruger A/S – Internal view of composting zone

10.2.11 Sevar Entsorgungsanlagen GmbH (Germany) – Agitated bin (rectangular)

Composting feedstock, or material that has gone through an earlier Sevar tower composting process (see Section 10.1.3) enters a composting hall through a dosing conveyor that deposits material for composting into one of a number of bays. The material is moved along each of the bays by a turner that runs along the top of the bay walls (Figure 12-20).

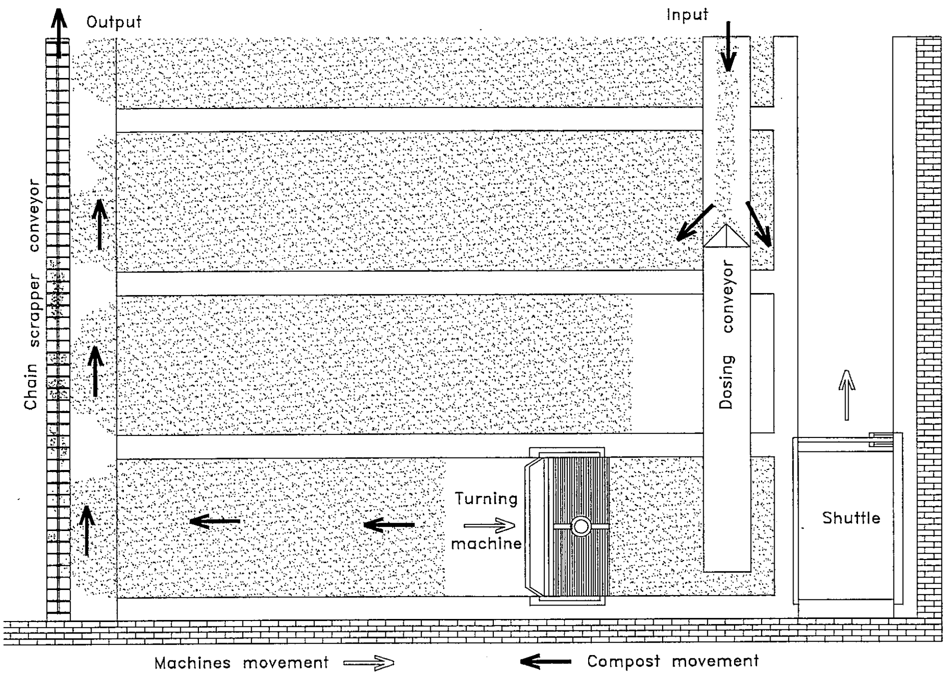

Figure 10-20: Sevar composting hall from above

Once the machine is in position, the turner is lowered into the bay and mixing begins. Each pass of the turner mixes the material and moves it 2.5 metres along the bay. As space is created at the dosing end of each bay, fresh feedstock is added. The turner machine is moved from one bay to another as required by a shuttle system. The volume of the composting hall has been designed to be as small as possible, thereby reducing the volume of odour-carrying air requiring treatment. Air is supplied by means of fans linked to the perforated floors of the bays. The required moisture of the composting waste, about 60%, is maintained by an integral watering system that uses fine mist sprays to add water to minimise the generation of leachate.

The material takes between 8 to 12 weeks to travel the full length of the bays. This can be adjusted by changing the frequency and speed of the turner. Exhaust air from the waste reception area, the sewage sludge dryer and the composting hall is taken through an ammonia scrubber and biofilter to remove odours before the air is released to atmosphere. The biofilter loading is limited to 100-120 cubic metres of air per square metre of filter area, ensuring that the efficiency of the biofilter is not compromised.

At the end of each bay the finished compost is discharged on to a conveyor that transports the material to the post-composting area for screening. The screened material is then stacked in heaps 4.5 metres high using a front-end loader for maturation.

10.2.12 Farmer Automatic (USA) – Agitated bin (rectangular)

This composting system (Compost-A-Matic) is based upon a continuously agitated bay principle. The concrete bays are one metre deep, 2-6 metres wide depending upon the throughout volumes, and 75 metres long (Figure 10-21). The 2 metre wide bay has a daily capacity of 4.6 cubic metres of feedstock, while the 6 metre wide bays has a daily capacity of 13.5 cubic metres.

Figure 10-21: Farmer Automatic composting bay

A turner mounted on the bay walls (Figure 10-22) is used to mix, aerate and turn the composting waste and move it 2 metres along the bay at each pass.

Figure 10-22: Farmer automatic turner

The bays are constructed under a plastic polytunnel or Dutch barn to protect the compost and equipment from adverse weather conditions. Odour-carrying air is extracted and passed through a biofilter.

10.2.13 Biomax Inc. (Canada) – Agitated bay (rectangular)

The agitated bay composting technology developed by Biomax Inc is referred to as the Robotcompost system and is a development of the earlier Triple A process. Each bay is 4.2 metres wide and 2 metres deep. The length of the bay will depend upon the throughput of the system and the retention time required. A typical length would be 50 metres for a 14-day retention time. Shredded and mixed feedstock is fed into one end of the bay and is gradually moved down the length of the bay by a turner mounted on the bay walls. The turner can be moved from one bay to another as required. Compost reaching the far end of the bay is removed by conveyor. The floor of the bays contains a forced-air system to allow the composting waste to be aerated and a degree of temperature control to be maintained. Hoods are mounted above the bays to contain any odours produced. These are linked to biofilters. The composting process is controlled by monitoring and adjusting the speed of agitation, the level of aeration and the composting temperature. The entire composting system is constructed within a building.

Typical Sites:
Ange-Gardien, Ottawa, Canada: 40,000 tpa of pulp and paper residues, 1995.

10.2.14 Lurgi Umwelt (Germany) – Agitated bin (rectangular)

The Frankfurt-based Lurgi Umwelt Group has acquired the Wendelin composting technology of the Swiss company Buhler AG.

Prepared feedstock is delivered by conveyors to a feed bridge that crosses the rectangular composting area. The feed bridge is movable and is used to form a wide, flat-topped pile of material up to 3.3 metres deep, divided lengthways into several sectors, on top of a perforated floor. A second bridge spans the composting area and can move to any position. A carrying mechanism is attached to this second bridge, and to this is attached the bucket wheels and conveyor of the turning machine. The rotating bucket wheels pick up the composting waste and transfer it to the conveyor as the bridge moves across the width of the composting area (Figure 10-23). When it reaches the edge, it moves forward 20 cm and reverses direction. This action allows 20 cm wide slices of material to be processed. Water can be added at this stage if required. The bridge continues to move in this way to process the entire composting area, starting from the most mature end of the heap and finishing at the end where fresh feedstock is added. The mechanism is then lifted and returned to the original position so that the process can be repeated.

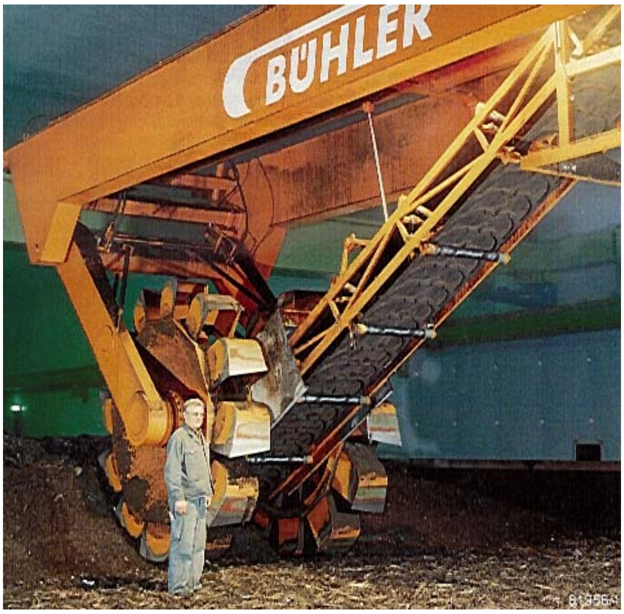

Figure 10-23: Lurgi (Buhler) compost turner

Air is blown through the perforated floor to provide oxygen and to provide a degree of temperature control. The whole composting area is contained within a building. The same turning mechanism is used to remove finished compost from the composting area and to place it on an emptying conveyor that runs the width of the composting building.

10.2.15 OTV (USA) – Agitated bin (rectangular)

The Siloda composting process (Mousty and Reneaume 1984, Levasseur 1987, Mousty and Levasseur 1987, Anon 1990a, Anon 2000a) supplied by OTV was originally developed in France for the composting of household waste. Composting takes place in rectangular bays placed side by side within a building (Figure 10-24).

Figure 10-24: OTV composting bays

The bays are open at both ends to allow the movement of a horizontal shaft paddle wheel, travelling on top of the low bay retaining walls. Once each bay is filled it is left for 48 hours while air is blown through it via a perforated floor linked to fans. The paddle wheel is used to turn the composting waste every two days. As the paddle wheel move through the compost, it picks the compost up and transfers it to an auger that lifts the material into the next bay. The paddle wheel can then be transferred to another bay as required.

10.2.16 Sutco (Germany) - Agitated bin (rectangular)

This is another agitated bay system that has been used in a number of facilities. Shredded and mixed feedstock is fed into one end of the bay where it is gradually moved along to the other end by means of a wall-mounted turner (Figure10-25). This picks up the composting waste and transfers it to an elevator that deposits it behind the turner as it moves along.

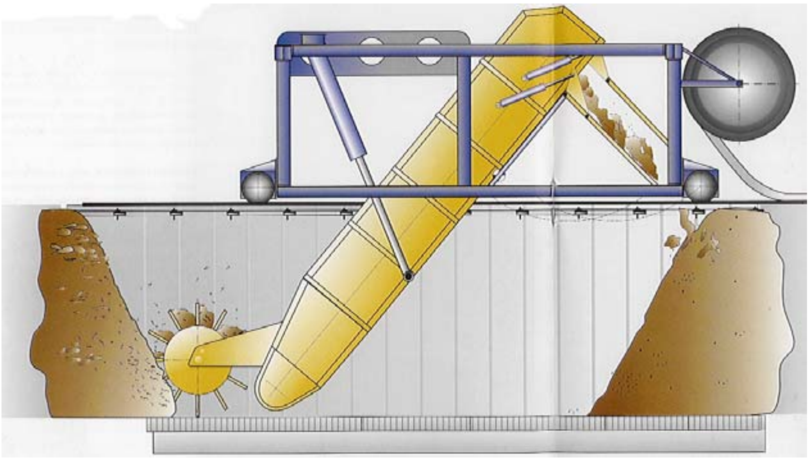

Figure 10-25: Sutco (Biofix) – schematic side view of turner in bay

The system is set up within a building. Odour-carrying air must be extracted and passed through a scrubber and biofilter system.
Typical Sites:
Landkreis Weilheim-Schongau – 16,000 tpa mixed waste
Firma Earthgro, Lebanon, USA – 80,000 tpa mixed waste
Dusseldorf/Mettmann - 25,000 tpa mixed waste

10.2.17 Wright Environmental Inc. – Continuous tunnels

This composting system consists of a computer-controlled, insulated, double-walled container lined with stainless steel (Goldstein 1996, Sinclair 1996, Farrell and Goldstein 1997, Anon 1998k, Block and Farrell 1998, Block and Goldstein 1998, Chaves 1998, Composting Association 1999c) (Figure 10-26). Various size systems are available ranging from 2 – 15 tonnes of feedstock per day. The company states it is possible to produce systems capable of taking up to 300 tonnes per day through the use of multiple input, processing and emptying channels.

Figure 10-26: Wright Environmental continuous composting system

Each container is divided into three composting zones, each with its own air supply. These are monitored and controlled separately. These three composting zones are separated by two mixing zones to increase the homogeneity of the composting waste.

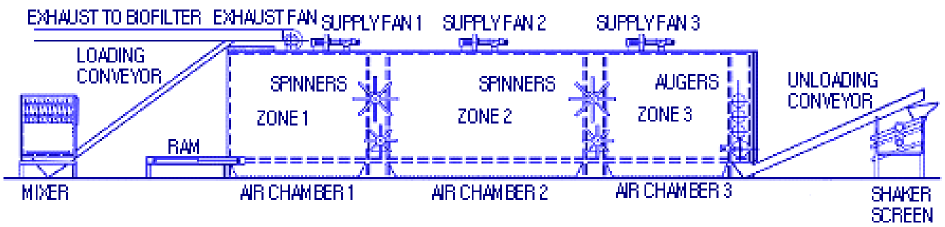

Figure 10-27: Wright Environmental system showing the air and mixing zones.

Feedstock is fed into a drag chain mixer prior to being transported by conveyor to composting zone 1 through a hydraulic door. Forced air is supplied to this zone and is continuously recirculated. The composting mixture is then moved down the length of the container, through each of the mixing and composting zones. In each composting zone the temperature, humidity and air flow rates are controlled to maintain optimum conditions for composting. Oxygen levels are not allowed to drop below 17%. Exhaust air is extracted from the container and passed through a biofilter for odour treatment. Typically, the retention time is 14 days, after which the compost is removed from the last section of the container by an unloading conveyor and passed through a screen. Oversized material is used as an amendment for the subsequent feedstock. The finished compost is normally allowed to mature for four or more weeks. The system requires access to an electricity supply, a water supply, and to a sewage outflow for any surplus water produced. An alternative design will allow the recirculation of excess water. The system can be situated out of doors or under cover to protect the filling and emptying operations.

Typical sites:
Isle of Wight: 3 tunnels, each with a capacity of 5,000 tpa. Kitchen waste, shredded garden waste.

10.2.18 BioPlan A/S (Denmark) – Continuous tunnels

This composting system, housed in a building (Figure 10-28) consists of three sections: a receiving and mixing zone, a processing zone, and an output zone (Jespersen and Thostrup 1992).

Figure 10-28: BioPlan Composting plant at Odda, Norway

Shredded and mixed feedstock is fed into the processing zone by means of an automated conveyor. The processing zone is a closed, insulated container with continuous input of waste and output of product (Figure 10-29).

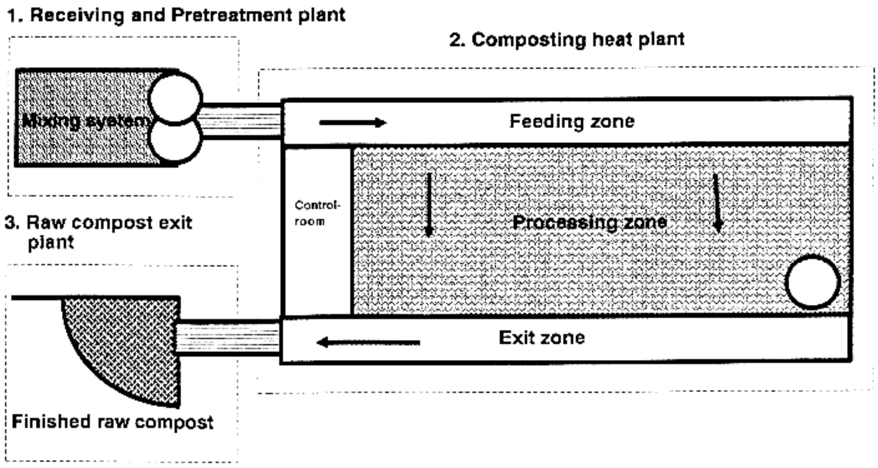

Figure 10-29: Process schematic of BioPlan composting system

The composting waste is mixed by means of a programmed vertical mixing drum (Figure 10-30). Aeration is provided by means of a perforated floor.

Figure 10-30: Mixing mechanism for BioPlan composting system

A residence time of two weeks is normal, with finished compost leaving through the output zone. It may then be dried or stacked for maturation.

Air leaving the process zone is taken through a chemical scrubber and a biofilter. Drainage water is recirculated to the composting waste. The system can be equipped with a heat exchanger to dissipate excess heat produced by the composting process. This waste heat can be used to dry the finished compost or to generate water at a temperature of 58°C. A computer monitors the temperature of the processing zone, outside temperature, water flow, the oxygen content in the process air, energy consumption and energy production. Sound insulation is reported to limit noise to a maximum of 60 dB during the day and 45 dB at night.

Facilities can range in size from between 50 and 1,000 m^3 intake per day. Typically, a 12,000 tpa plant can be filled every day with up to 40 tonnes (60 m^3) of feedstock each day, (Jespersen 1991).

Typical Sites:
Odda (Norway)
Holstebro (Denmark) (1990) c. 1,800 tpa

10.3 Batch (non-flow) systems

The three main types of batch container composting systems are considered in the following sections.

10.3.1 VAR Technologies (Netherlands) – Open bay

In this first batch system, mixed and shredded feedstock is filled into large, open-air bays made on a concrete base with concrete walls (Figure 10-31). The bays are open at the top. The floor of the bay is perforated and laid on a series perforated pipes or on some other mechanism that allows air to be blown or sucked evenly through the floor and the composting waste . The entire bay is filled at the same time or within a few days. Once filled, it is covered with over-sized fractions from screened finished compost. This, partly reduces odour release.

Figure 10-31: VAR composting system – aerial view of bays

The use of a perforated floor (Figure 10-32) offers considerable advantages over a simple aerated static pile system that uses a single perforated pipe. This first stage takes about 3 weeks. Temperature measurements can be taken at a number of points and it is possible to adjust the rate of airflow to provide a degree of temperature control. The material is not agitated or moved during the three-week period.

Figure 10-32: VAR composting system – aeration system between bays

At the end of three weeks, the composted material is removed and screened. The fraction less than 40 mm is transferred to a secondary composting area. Airflow and temperatures are controlled in a similar way to the first composting stage. After 8 weeks, the compost is transferred again to a second screening area. The fraction less than 15 mm is the final compost product while the 15-40 mm component is used as the covering layer on the next batch of compost. Process air leaving the composting bays is passed through a biofilter (Figure 10-33).

Figure 10-33: VAR biofilter system

10.3.2 R.A. Rucklidge (UK) – Open bay

The mushroom composting industry in the UK has recently started to change from open air windrow composting to an enclosed 'Phase I' system. Other countries have used this form of composting for some time (Gerrits et al. 1995).

In the Rucklidge system, a simple concrete bunker, up to 6 metres wide and up to 40 metres long, with a ventilated floor is used to hold up to 300 tonnes of a wetted straw/chicken manure mixture that forms the feedstock for the preparation of compost used to grow the commercial white mushroom. The bunker is filled by a front-end loader. The bunker may be built in the open air or within a building.

Air is blown by fans through the floor and the composting waste. There is no recirculation of the air. The air supplies the required oxygen and provides a degree of temperature control. The system is computer controlled, with the computer using oxygen and temperature data to control the process. Although designed for the mushroom industry this concept could in principle be used to compost other wastes such as those separated from MSW.

10.3.3 Traymaster Ltd. (UK) – Open bay

The UK company Traymaster supplies an open-topped, aerated non-agitated bay system for the manufacture of mushroom compost from wetted straw and chicken manure (Figure 10-34).

Figure 10-34: Traymaster non-agitated bay system

This system could in principle be used for the composting of other wastes such as those separated from MSW.

10.3.4 Gicom b.v. (Netherlands) - Fixed batch tunnels

Non-flow batch tunnels have been used for many years in the preparation of compost from straw and animal manures for the commercial cultivation of the white mushroom, Agaricus bisporus, (Vedder and Smits 1982, Anon 1990, Vestjens 1994). Similar systems are increasingly being used in the contained composting of other organic wastes.

The Gicom batch tunnel system provides a mechanism for composting a wide variety of organic wastes, including mixed MSW, source-separated household waste, green waste and biosolids, at near optimal conditions in a fully enclosed environment (Lokin and Oorthuys 1994, Inbar 1996, Lindburg 1996, Lindburg 1996a, Oorthuys and Scharff 1996, Hayes 1998, Cioli et al. 1999).

The tunnels are rectangular concrete boxes typically 4 metres wide, 4 metres high and up to 25 metres long (Figure10-35). Different sizes of tunnels are available for different volumes of feedstock (from 50 tonnes to 200 tonnes per tunnel). Additional tunnels can be added as necessary. (Figure 10-36).

Figure 10-35: Gicom composting plant (Deurne) for 35,000 tpa of MSW

1. Intake of MSW 2. Hopper
3. Rotary screen 4. Hand-picking line
5. Shredder 6. Input conveyor
7. Automatic filling machine 8. Automatic emptying machine
9. Output conveyor 10. Ballistic separator
11. Mature compost storage 12. Fresh air input for tunnels
13. Exhaust air from tunnels 14. Air humidifier
15. biofilter 16. Control room

Each tunnel consists of concrete sidewalls and roof, with a perforated concrete floor constructed on top of a series of aeration pipes. One end of the tunnel is closed by a concrete wall while the other consists of an insulated sliding door that is removed during filling and emptying. The aeration system is computer. controlled. The fan blows air into the floor pipes and through the perforations in the floor, through the composting waste in the tunnel. This air is recirculated to the fan and can be combined with fresh air drawn in from the area used to fill the tunnels. Dampers, under computer control, are situated at various points in the ducting to allow different combinations of fresh air and recirculated air, achieving a very tight control of the environment within the tunnel (Finstein 1993).

Temperature probes are situated at a number of points in the compost, at the point where air enters the aeration pipes and at the point where fresh air enters the tunnel. There is very little variation in compost temperature throughout the tunnel (Lokin and Oorthuys 1994, Scharff and Oorthuys 1994, Oorthuys et al. 1995)

Oxygen probes, humidity probes, carbon dioxide probes and pressure sensors are also employed. The data obtained from these probes is sent to, and stored by, the computer. All of the data can be displayed at any time in a number of formats. Data may also be extracted for statistical analysis. The data normally recorded for each tunnel include:

- Oxygen consumption (g/kg; g/h);
- Total oxygen consumption (tonnes);
- Water evaporation (g/kg; g/h);
- Total water evaporated (tonnes);

- Energy content of different air flows (J/kg; J/h);
- Total amount of emitted energy (J);
- Total amount of recirculated air (m^3);
- Total amount of fresh air input (m^3); and
- Water content of composting waste (%).

Feedstock, typically shredded and mixed to provide a uniform starting material, is placed in the tunnel by means of a front-end loader or filling conveyor to a depth of about 2 metres. Care is taken to ensure even filling. The loading density is typically 500 kilograms per square metre of floor space. After filling, the insulated door is put in place and composting begins. The area used for filling and emptying is normally within a building to contain any odours that might be generated at this stage.

The environment in the tunnel is under the control of a computer. (Figure 10-36). The required environmental conditions are fed into the computer by the operator and the system is operated by the computer. The process can be monitored and controlled by a remote modem link if required.

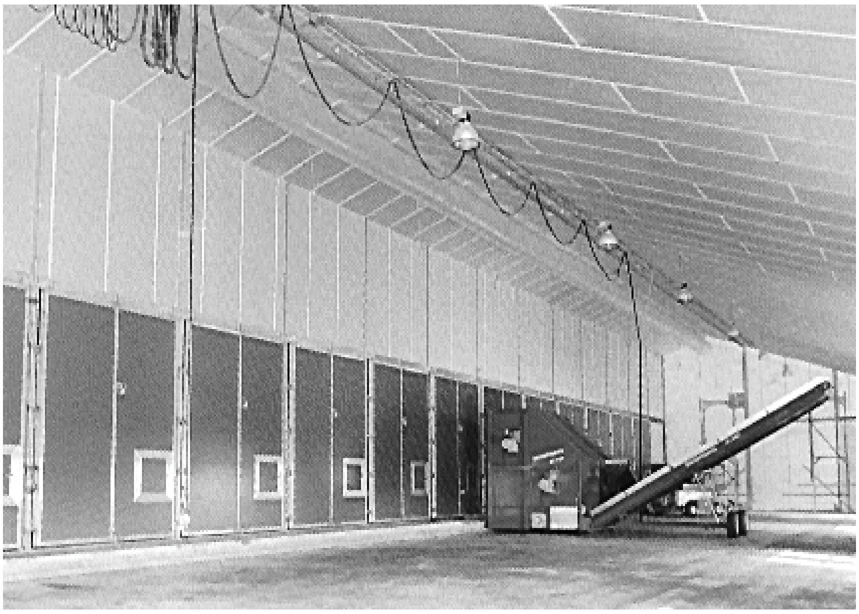

Figure 10-36: Gicom composting tunnels viewed from filling area

At the start of the procedure air is blown in to ensure that the composting mixture is kept aerobic and brought to a uniform temperature. Dampers to control the recirculation are then adjusted to allow the temperature throughout the entire tunnel to rise to about 58°C. The compost is kept at this temperature for 8 hours or more to pasteurise. The compost temperature is then allowed to drop to about 45 - 50°C to carry out the main thermophylic composting stage under optimum conditions. At the end of the process, fresh air is blown into the tunnel to cool the compost to ambient temperatures. The entire process takes 14 days.

The small amount of leachate and condensate generated during the composting process is automatically drained into a collection tank, and is used to humidify exhaust air streams within the biofilter system (see below) and to control the moisture of the compost within the tunnels. Overall no wastewater is generated by the operation.

Odorous exhaust air, is removed from each tunnel and taken by a common duct to one or more biofilters (Figure 10-37). Before the air enters the biofilters it is cooled, and any ammonia present is removed by a wet scrubber. The temperature of the air, along with its humidity and pressure are measured. The temperature of the biofilter is also monitored. This allows the temperature of the biofilter to be maintained at optimal levels to ensure the efficient cleaning and bio-degradation of odorous compounds. After leaving the biofilter, the air is essentially free from offensive odours. Biofilter emission levels in the order of 50-100 Odour Units/m^3 are typical.

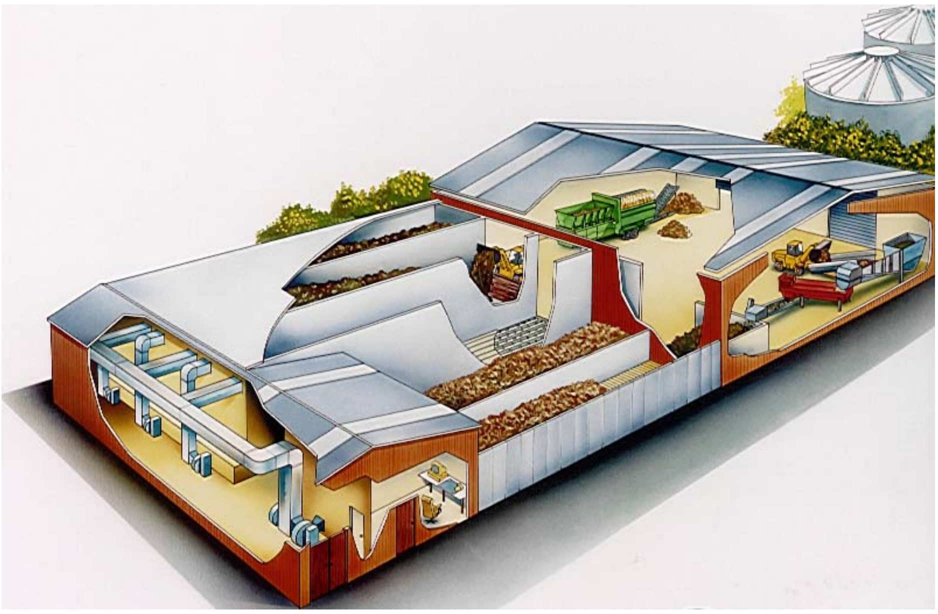

Figure 10-37: Gicom batch tunnel system (three tunnels with two open biofilters)

The working environment for staff involved in filling, emptying and otherwise working in the facility is also under control. Air conditioning of the filling/emptying area allows the air to be totally changed at least once every hour. Misting sprays and dust/spore filters may also be used at points outside the tunnel where dust can be generated. It is recommended that, if front-end loaders are used to fill and empty the tunnels, over-pressure cabs should be used to protect the driver from dust and spores.

There are many variations in the way that the tunnels can be used for composting. In its simplest form, composting can be carried out for 14 days and the resultant odour-free compost removed for maturation elsewhere on site or at another site. Alternatively, the composting waste can be removed from the tunnels after 10-14 days, screened to remove oversize material and inerts, and then refilled into a tunnel for a further 10-14 days treatment. The tunnels can also be used partially to compost and dry MSW over a 5-7 day period. Which method is chosen will depend upon the nature of the waste and the compost quality standard to be achieved. Typically, the Dutch (BRL) standard and the German (LAGA M10) standard can be met for compost made from source-separated domestic waste after 14-21 days of composting. The space requirements for this type of facility will depend upon which of the above methods is chosen, and whether finished compost is stored on site. The following Table 10-1 summarises some of the options:

Table 10-1: Approximate area requirements for Gicom batch tunnel system

Annual input capacity (tpa)	First stage composting	Second stage composting	Area required (m^2)
20,000	In tunnels	In tunnels	3,500
20,000	In tunnels	In windrows	4,000
50,000	In tunnels	In tunnels	7,400
50,000	In tunnels	In windrows	7,900
75,000	In tunnels	In tunnels	9,100
75,000	In tunnels	In windrows	10,100

Cioli et al (1999) used a Gicom batch tunnel system to compost the organic fraction of municipal solid wastes and similar wastes. The material was composted for 14 days in the tunnels, removed, screened, and refilled into the tunnels for a further 14 days composting. Since a 50% reduction in volume was achieved during the first stage of composting, only half the number of tunnels was needed for the second stage of composting. The tunnel composting was followed by maturation for 30-40 days. Cioli et al. found that the tunnel system made it possible to stabilise a variety of organic wastes in this way, reaching respiration activity in the order of 150 – 200 mg/kg of 0_2 of volatile solids/hour. The resultant compost had a carbon: nitrogen ratio of 11-12:1, and allowed a germination rate of 90-100% in toxicity trials.
The main advantages of this type of composting operation are:

- High degree of process control;
- Short composting period (14-21 days);
- Ability to compost a wide variety of wastes;
- Ability to produce a range of compost products;
- Sophisticated odour control;
- No mechanical devices in tunnel to corrode;
- Separation of workers from composting environment;
- Automatic computer control of process with full record keeping;
- No waste water generated;
- Proven technology; and
- Re-use of process energy.

Typical Sites:
Ipswich (UK): 14,000 tpa green waste and sewage sludge, 1997
St. Oedenrode (Netherlands): 3,000 tpa, 1990
Deurne (Netherlands): 25,000 tpa, 1992
Twente (Netherlands): 60,000 tpa, 1993
Venlo (Netherlands): 75,000 tpa, 1993
Rotterdam (Netherlands): 70,000 tpa, 1997

10.3.5 Herhof-Umwelttechnik GmbH (Germany) – Fixed batch tunnels

The basic Herhof system is called the Rottebox, and is constructed from reinforced concrete with a capacity of 60 cubic metres (Figure 10--38). The box is airtight and insulated to allow efficient control of the composting environment (Gies 1996, Gies 1996c, Kubocs and Gruneklee 1996, Anon 1998o, Roulston 2000). Shredded, mixed feedstock is fed into the box by of an automatic conveyor to a depth of about 2 metres.

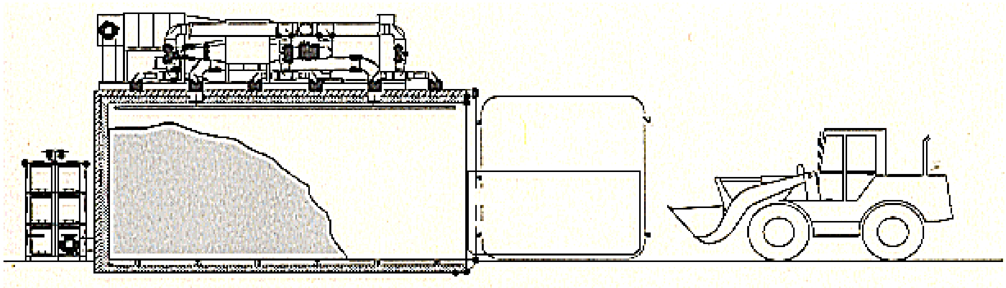

Figure 10-38: Herhof composting box (side view)

The floor of the box is perforated, and fans blow air through the floor, through the compost, and back to the fan again via ducting. Fresh air is introduced in a controlled way to control the oxygen levels and temperatures. The floor is divided into six sections and the air flow to each can be independently controlled. Air leaving the box is passed via a heat exchanger through a biofilter to remove the remaining odours. The heat exchanger cools the air preventing the microbial population of the biofilter from being stressed by too high a temperature. Any leachate produced is recirculated within the box. The whole control system is computer controlled.

After 7-10 days the compost is removed from the box by an automatic scraper conveyor that can move from box to box as required. The composted waste is either used immediately or taken through a windrow composting maturation stage, depending upon the intended use for the compost.

Typical Sites:
Lahn-Dill-County, Asslar (German): 120,000 tpa, 1992
Limburg-Weilburg, Beselich (Germany): 36,000 tpa, 1993

10.3.6 Waste Treatment Technologies (WTT) (Netherlands) – Fixed batch tunnels

The WTT system involves the pre-treatment of waste, the composting process itself, and a post-treatment stage.

In the pre-treatment stage, incoming MSW waste is weighed and sorted, and the mainly organic component is tipped into a low-level bunker within a building. This waste is then moved by a grab crane into a hopper linked by a conveyor to parallel separation lines. The waste is crushed and shredded in a mill and then passes through a screen onto a conveyor belt under the mill. The light component is removed pneumatically to a cyclone and then carried by a conveyor to an RDF (refuse derived fuel) bunker. The remaining material is taken through a rotating screen, where a magnet removes ferrous components to a separate conveyor belt. The screen separates the material into a fine fraction of non-combustible material has been used as cover material for landfill sites, organic material that is passed to the composting plant, and oversized material that is transferred to the RDF bunker.

The organic waste stream from the pre-treatment stage (<80 mm) is transported by conveyor to the composting filling hall. In the process, it passes under a second magnetic separator to remove ferrous contaminants. The material is then fed into the batch tunnels (Figure 10-39) and the tunnels are closed.

Figure 10-39: Inside view of a Waste Treatment Technologies tunnel

The floors of the tunnels are fitted with pipes linked to an air supply unit Air enters the tunnels through spigots connected to these pipes that open into the tunnel floor. (Figure 10-40).

Figure 10-40: Aeration pipes in tunnel floor during construction showing spigots

Air is recirculated through the tunnels by means of ducting, with fresh air being introduced as required to control temperature and maintain adequate supplies of oxygen. Exhaust air leaving the tunnels is taken through a biofilter to remove odours (Figure 10-41). The whole process, including temperature, rate of airflow, oxygen levels, valve movement, is computer controlled.

Figure 10-41: External biofilter and ducting taking exhaust gases from tunnels

After the tunnel composting stage, the composted material is taken through a trommel screen to remove particles greater than 45 mm. The larger particles can be used as RDF. The smaller particles are returned to the tunnels for a second period of composting. Only two tunnels are required for this second stage for every three used in the first, because of the reduction in the volume of the material brought about by composting and screening.

After the second tunnel composting stage, the compost is removed from the tunnels by automatic equipment and transported to a storage area where it is again screened to produce three products: <12 mm, 12-23 mm, and >35 mm. Plastic and stones can be removed at this stage. It is possible to install an incinerator, in conjunction with the composting plant, in order to utilise the RDF material separated at the pre-composting stage.

Typical Sites:
Klosterforst, Germany. 20,000 tpa of source separated organic waste. 5 tunnels. December 1996.
Oldenburg, Germany. 25,000 tpa of source separated organic waste. 12 tunnels. May 1997
Stadhagen, German. 20,000 tpa of source separated organic waste. 7 tunnels. May 1997.

10.3.7 Dalsem-Veciap b.v. (Netherlands) – Fixed batch tunnels

The Dalsem-Veciap batch tunnels follow the same general format as those previously described: a computer controlled, enclosed, rectangular container supplied with recirculated forced air through a perforated floor. The tunnels can hold between 30 and 350 tonnes of composting waste. Filling and emptying can be by means of a front-end loader or an automatic filling conveyor. A minimum oxygen level of 15% is maintained and the main composting stage is carried out at 50°C. Oxygen level, temperature and the other set points are pre-programmed, and monitored and controlled by a process computer.

Composting is carried out for 7 – 14 days. The material is then removed from the tunnels, re-mixed, moistened and placed in second tunnel for 7 – 21 days. Alternatively, this second stage can be carried out in windrows on a concrete pad within the composting building. After the second stage, the compost is normally allowed to mature for 6 – 8 weeks.

The filling, composting, emptying and storage all take place within a fully enclosed building, kept under negative pressure by air being pulled into the composting tunnels. This arrangement limits the risk of odours escaping the facility. Odour-carrying air leaving the tunnels is transferred to a common duct and taken through a condenser linked to an evaporation cooling tower. The air is then taken through a wet scrubber to remove ammonia and dust and to control the humidity and finally through a biofilter before being released to atmosphere. Any leachate or condensate produced is taken back to the tunnels.

Typical Sites:
AVL Maastricht (Netherlands): 60,000 tpa organic wastes, 1995.
GFA Landkreis Dachau (Germany): 1,200 tpa organic wastes, 1992
MKW Aurich (Germany): 60,000 tpa (40,000 tpa source-separated, 20,000 tpa garden waste), 1997

10.3.8 Compost BASystems b.v. (Netherlands) – Fixed batch tunnels

The BA systems batch tunnel is a static, closed container using forced air under computer control, delivered through a perforated floor, to manage the composting process. The tunnels are 3-4 metres wide and 10-30 metres long and can hold 50-120 tonnes of composting waste, equivalent to an annual processing load of 1,250-3,000 tpa per tunnel, assuming a 14 day processing period. Additional tunnels can be added as required to increase the throughput.

The tunnels are filled by an automatic conveyor system to a depth of 2-2.4 metres. The tunnels are then operated under computer control by monitoring and controlling air and compost temperature, oxygen and carbon dioxide, and humidity levels. A dragnet can be placed on the floor prior to filling. This is then pulled out using a winch to empty the compost at the end of the process.

Exhaust air from the tunnels can be taken through a biofilter, and any leachate produced can be recirculated to the compost.

Typical Sites:
Liezen (Austria): 3,000 tpa biowaste, 1992.
Allerheiligen (Austria): 25,300 tpa biowaste, 1996
Eichenzell (Germany): 22,000 tpa, 1998

10.3.9 Double T (Canada) – Fixed batch tunnels

These batch tunnels have been developed from those built for the mushroom composting market. The general concept of the tunnels, and their method of control, are similar to those already described. Tunnel size varies from 6-150 tonnes.

10.3.10 Gicom b.v. (Netherlands) – Mobile batch tunnel

The same basic technology developed for the large, fixed batch tunnels described above has also been transferred to smaller, mobile or semi-mobile systems, (Goldstein 1998, Block and Farrell 1998)

This system is based upon a smaller version of the Gicom batch tunnel described earlier in this report. It consists of a number of stainless steel, corrosion-resistant, airtight and watertight modular container units that are supplied pre-assembled (Figure 10-42). These containers are normally 3 metres high, 3 metres wide and 13 metres long. Each container can process about 1,000 tpa.

The setting up of an installation, including the attachment of a wet scrubber and biofilter, can be accomplished in a couple of weeks. This type of system is suitable for facilities with input levels between 500 and 7,500 tpa, with each container typically holding a 40 tonne batch of composting waste. The capacity of a facility can be increased by adding more containers as required.

Figure 10-42: Gicom modular composting containers

Each container has a perforated floor, similar in concept to the perforated floors in the static versions, connected by ducting to an aeration fan. As in the static versions, each container has temperature, humidity, and oxygen levels monitored and controlled by computer The wet scrubber and biofilter ensures that process air released from the system is essentially odour free.

The containers are filled by a small front-end loader, and after 14 days composting are emptied in a similar way.

10.3.11 NaturTech Composting Systems Inc. (USA) – Mobile batch tunnel

The design of the NaturTech composting system is based upon computer-controlled 40 cubic yard (31 m^3) roll-on roll-off (RORO) containers (Goldstein 1996, Goldstein 1997, Block and Farrell 1998, Block and Goldstein 1998, Goldstein 1998)

Each container is about 6.9 metres long, 2.3 metres wide and 2.4 metres high and made from epoxy-painted steel. The roof of the container is hinged to allow filling from above. A removable stainless steel, perforated floor is laid on top of the floor of the container. The space beneath the perforated floor is connected by ducting to a freestanding fan and air supply system.

The concept of control of the composting system is rather different to that of the fixed batch tunnels described earlier. Air is forced by the fan, through the perforated floor, through the composting waste and out through an exhaust pipe. There is no recirculation of air within the container. Air leaving the container can be taken via ducting to a 20 yard^3 (15 m^3) biofilter fitted with an aeration floor and filled with biofilter material.

Additional containers can be added to increase throughput. Containers may be joined together by common air ducting and then joined to a shared biofilter.

Typical Sites:
Mankato (USA): 1,300 tpa of green waste (1992). 7,800 tpa (1996)
Hutchinson (USA): 1,300 tpa of green waste (1992). 7,800 tpa (1996)
Saint Louis (USA): 2,080 tpa of commercial waste (1996). 13,000 tpa (1997)

10.3.12 Green Mountain Technology (USA) – Mobile batch tunnel

This system is also based upon the concept of a roll-on roll-off (RORO) container (Parzych 1995, Goldstein 1996, Farrell and Goldstein 1997, Block and Farrell 1998, Block and Goldstein 1998, Goldstein 1998). Each container is 6.4 m long, 2.3 m wide and 2.7 m high, and has a capacity of 38 cubic yards (29 m^3). Each container is loaded by conveyor through temporarily opening one end of the container. The containers are fitted with stainless steel perforated floors. Aeration is supplied by a computer-controlled fan system that can serve a number of containers through common ducting. Aeration can be from the bottom to the top of the compost or from the top downwards. Exhaust air from the containers is taken into a common duct connected to a 30 cubic yards (23 m^3) open biofilters. Any leachate produced during composting is collected in a holding tank.

Compostable waste is delivered to a covered processing area where it is shredded and mixed to produce a uniform starting material. The prepared mixture can then be loaded into the containers in the covered area, the containers then being transported to the out of doors composting area (Figure 10-43). Here they are connected to the joint air supply and computer control system. If required, partially composted waste can be transported back to the processing area, tipped out, mixed, and modified as required, prior to refilling into the container. When composting is complete, (14-21 days) each container is picked up by a RORO transporter and moved to an area for screening.

Figure 10-43: Green Mountain Technology CompTainer batch tunnel (3 units)

Typical Sites:
Wilmington (USA): 1 CompTainer for sewage sludge and woodchips, 1994.
Arlington (USA): 1 CompTainer for green waste and stable manure, 1996.
Westport (USA): 3 CompTainers for sewage sludge, 1997.
Texas University (USA); 7 CompTainers for animal waste, 1997.

10.3.13 Lurgi (Germany) – Mobile batch tunnel

This is another composting system based on the concept of RORO containers (Figure 10-44). A computer-controlled aeration system, using a perforated floor, is employed to control the composting process. Odour-carrying exhaust air is taken through a biofilter.

Figure 10-44: Lurgi containers - showing containers stacked two-high

Large numbers of containers can be linked together to increase site capacity as required (Figure 10-45).

Figure 10-45: Lurgi composting containers – aerial view of composting facility

10.3.14 Von Ludowig (Germany) – Mobile batch tunnel

This is a computer-controlled, insulated, container-based system arranged in the form of modules (Figure 10-46). Each module consists of 8 containers linked to an integrated aeration system and biofilter. Each module is capable of processing about 3,000 tpa of organic waste. Typical sites have a capacity of 3,000-30,000 tpa.

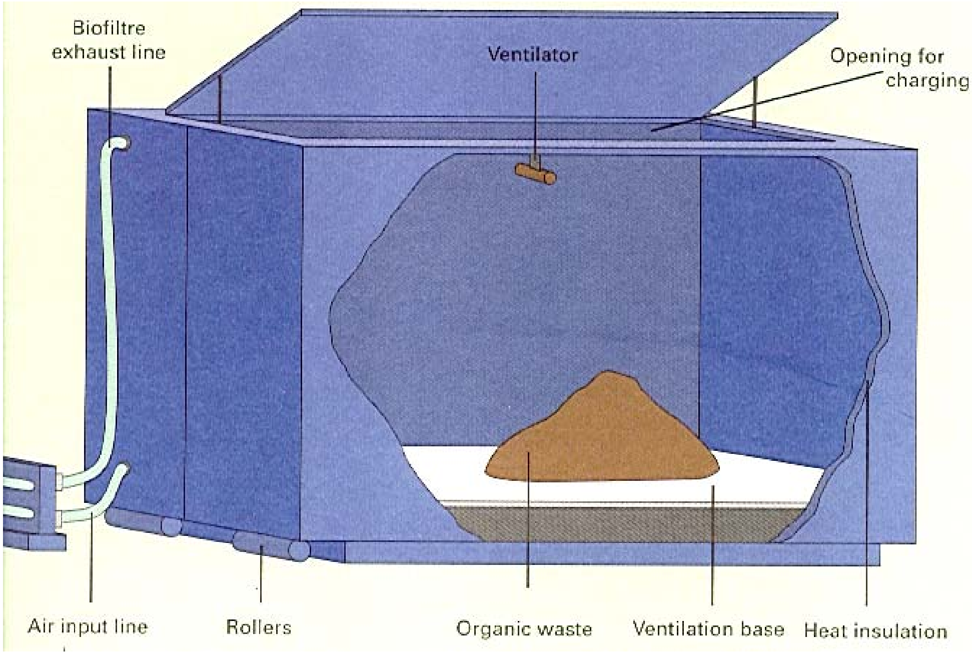

Figure 10-46: Von Ludowig composting unit - schematic

The containers are filled through the top and can be emptied by tipping. Ventilation is through a joint air supply unit (Figure 10-47).

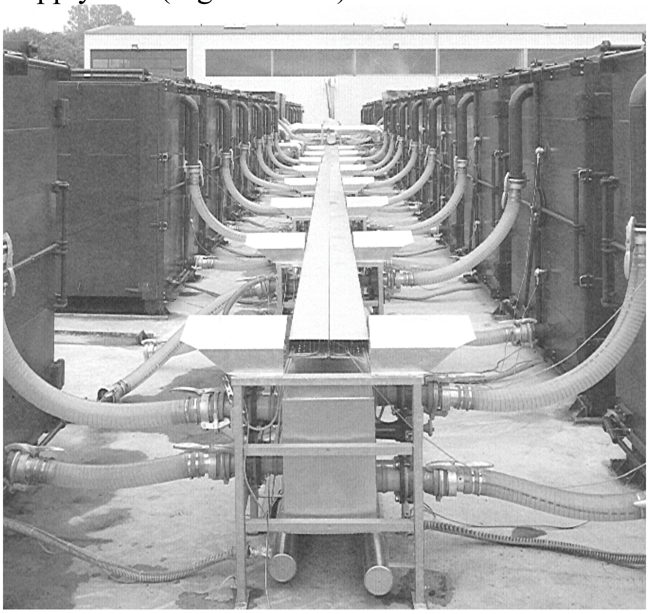

Figure 10-47: Von Ludowig container system – aeration supply to containers

Typical Sites:
Attenberge/Krei Steinfurt (Germany): 18,000 tpa household waste, 1995
Markranstedt/Landkreis Borken (Germany): 12,000 tpa household waste, 1995
Kuhstorf/Kreis Ludwigslust (Germany): 6,000 tpa household waste, 1995
Curitiba/Cuiaba (Brazil): 1,500 tpa household waste. 75,000 tpa sewage sludge, 1996

10.3.15 Alpheco Ltd. (UK) – Mobile batch tunnel

The Alpheco modular batch tunnel is based on RORO containers (Anon 1996c, Winship 1998). Shredded mixed feedstock is fed into a container from one end through a door that is then closed prior to the start of processing. The computer-controlled aeration unit then supplies pulsed air to the composting waste through a perforated floor. The direction of this air supply can be from the bottom up or the top down. Processing typically takes 14-28 days to produce a compost suitable for maturation. Any leachate and condensation produced during processing is recycled within the container. The container can be loaded on to a RORO vehicle to be transported after the end of processing and can then be tipped up for emptying.

Figure 10-48: Alpheco container system - end-on view of three containers

Typical Sites:
Anglian Water Services, Colchester (UK), 1998.

10.3.16 Stinnes Enerco Inc. (Canada) – Mobile batch tunnel

This is another small-scale batch container system. Stainless steel, insulated containers are fitted with a perforated floor to allow the introduction of air to control temperature and supply oxygen. Exhaust air is returned to an air-handling unit. This consists of a supply fan, heat exchanger, auxiliary heater and cooling tower. The heat exchanger and auxillary heater can be used to warm incoming air during cold weather. Exhaust air leaving the container is cooled where necessary in the cooloing tower and passed through a temperature controlled biofilter.

Typically, source separated organic waste is shredded, mixed and filled into the containers through a moveable roof. The containers, at this stage, are held within a receiving hall. This can be kept under slight negative pressure to limit odour release. When the container is full it is transported to a centralised facility and connected to an air-handling unit under computer control. Composting normally takes place for 10 days. Following this period of intensive composting the container is emptied on to a covered windrow composting pad, where it is kept for four weeks before screening. Following this initial screening it is windrow composted for a further four weeks before being screened again. A front-end loader is used to turn the windrows between screenings.

10.3.17 Biotech 2000 (USA) – Mobile batch tunnel

This U.S. patented composting system consists of a series of containers, each 40 feet (12.2 m) long, with a capacity of approximately 28 tonnes. These containers are fabricated in-place from concrete or concrete block, or as commercial containers manufactured off site. Forced air is supplied by means of a fan through a perforated floor. Unlike many other container systems that have single- pass aeration systems, this system recirculates the air through the compost. This recirculation can be used to warm rapidly newly filled feedstock to composting temperatures, and to limit the drying out of the compost. Exhaust air leaving the containers is taken through a biofilter.

10.3.18 Waste Mechanics – Mobile batch tunnel

A consortium of businesses, led by The National Environmental Technology Centre (NETCEN), which is part of AEA Technology, has developed a method of treating 10 - 20 tonne batches of organic wastes using fully contained modular vessels (Composting Association 1999b, Dunn et al. 2000). The project was funded by the Department of Trade and Industry, and the BOC Foundation. The technique - the Sirocco Composting System – is intended to fill the technology gap between capital-intensive contained composting systems, and open windrow composting. This system is marketed by Waste Mechanics Ltd.

The system is based on insulated 30 cubic metre RORO containers. It differs from many other systems based on these containers by having a continuous air recirculation feature. The integrated fan system is computer controlled. The method of controlling oxygen levels and temperature is the same as that used in the mushroom industry Phase II tunnels. The Phase II tunnels are used in the mushroom composting industry for the controlled pasteurisation (58-60ºC) and conditioning (45-50ºC) stages and employ computer-controlled recirculated air systems that provide excellent environmental control and uniformity of composting conditions.

Figure 10-49: Sirocco composting container with integral fan system

Typical Sites:
Thames Water: 2 units composting biosolids and woodchips

10.3.19 Traymaster (UK) – Mobile batch tunnel

The computer controlled Traymaster system is a single pass aeration system used to compost relatively small quantities of compost. The floor of the container is perforated to enable the supply of air for composting and air for temperature control. Although intended for the mushroom composting industry it can be used to compost other types of waste such as those seperated from MSW.

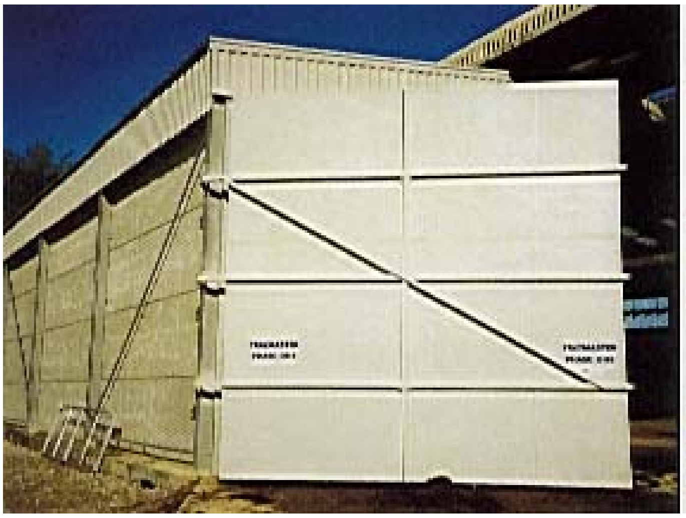

Figure 10-50: Traymaster Phase I tunnel

10.3.20 Rethmann Kreislaufwirtschaft GmbH (Germany) – Brick composting

Organic waste is delivered to a reception hall where it is loaded into on to a conveyor and delivered to a trommel screen. The screened material (<60 mm) then passes under an overhead magnet to remove ferrous materials. The material then enters a Brikollare press where it is formed into 60 kilo blocks. The blocks are structured so that air can penetrate to their centre. The blocks are then arranged in stacks on pallets with spaces between the brick to allow free air movement (Figure 10-51).

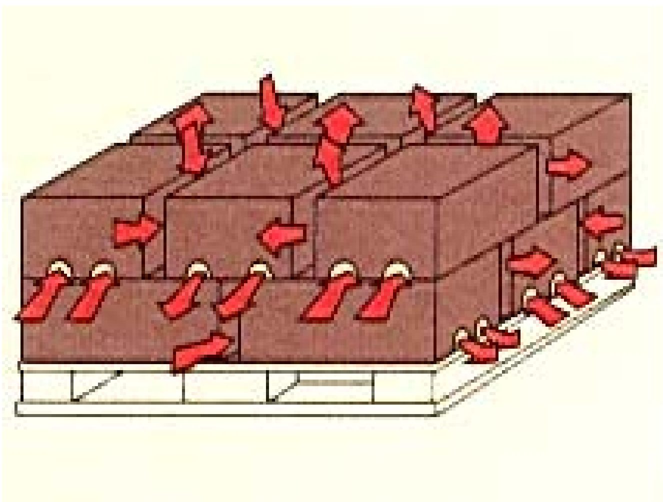

Figure 10-51: Rethmann composting bricks

An automated pallet transport system then delivers the stacked bricks into an aerated multi-level storage system for composting (Figure 10-52). Temperatures reach 70°C in the first few days and moisture levels drop by about 30%. A pasteurised product results. The bricks may then be broken up and taken through a maturation stage.

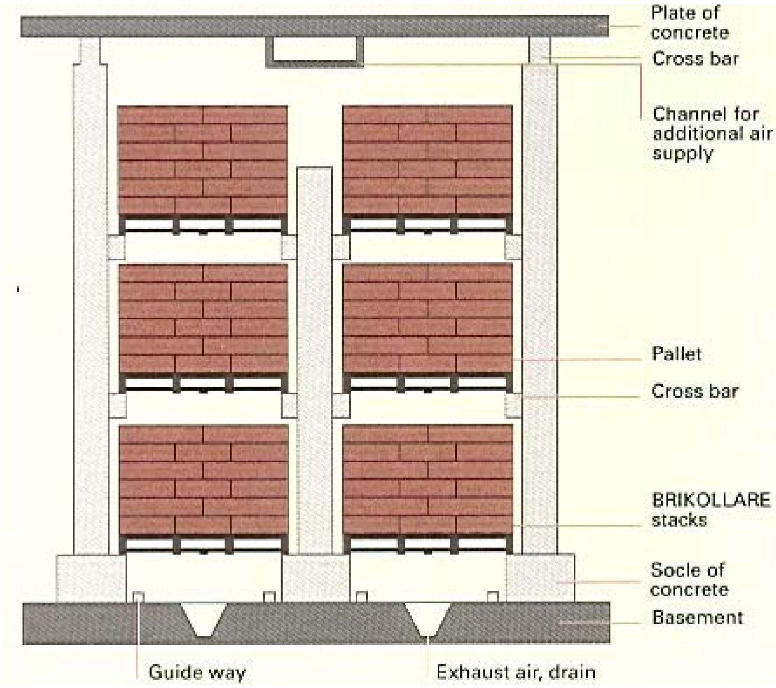

Figure 10-52: Rethmann composting system

10.4 Batch composting and Refuse Derived Fuel (RDF)

A number of composting systems have been developed, at the laboratory, pilot and commercial scale, that involve a partial recovery of the heat generated by the composting process (Jaccard et al. 1993) or the production of a refuse derived fuel.
Gicom B.V. (Netherlands)

Shredded mixed MSW is passed through a trommel screen with a 70 mm mesh. The fraction <70 mm is then taken into a Gicom batch tunnel composting system, either on its own or mixed with sewage sludge, (Nieveen 1997). Temperatures in the tunnel rapidly reach pasteurisation levels (60°C) and the temperature is then allowed to fall to 55°C, with oxygen levels at 15% and humidity at approximately 40%. Composting is carried out for one or two weeks. After one week's composting, MSW on its own produces pasteurised material at 15% moisture with a heating value of 12 MJ/kg. The material can then be compacted, baled, and used as fuel. If composting is continued for two weeks instead of one, an odour-free stable 'compost' is produced that can be cleaned up by screening to remove stones and ferrous components. This has been used as a soil improver or for tree planting compost.

10.4.1 Herhof Dry-Stabilate System (Germany)

This is a modification of the Herhof composting box discussed earlier in this report. Raw waste entering the facility is examined and large, unwanted contaminants are removed with a grapple. The waste is then shredded to <150 mm and transported by a fully enclosed conveyor to a Herhof composting box. The system used to fill the boxes has been modified to handle this type of material without the generation of large quantities of dust and bioaerosols. It takes the form of 'cassettes' combined with a telescopic feeder. The cassettes are positioned in front of the boxes and delivered to the composting box in a way that does not allow the release of dust or odours. Exhaust air from the cassettes is removed by a ventilator and taken to an odour treatment unit.

After the box is filled, the material is taken through a composting process for 7-10 days. The heat generated by the composting process is used to reduce the moisture level of the material in the box. The water vapour generated is removed by a ventilator and condensed to remove the water. This process reduces the moisture content of the material to <15%. The total mass of the material is reduced by 30-35% and the calorific value is increased by 35-40%, i.e. from 7-9 MJ/kg to over 11 MJ/kg. The dry stabilate can then be treated in one of two ways:

Dry stabilisation in combination with conventional refuse incineration:
In this method, the dry stabilate is screened into two components – high-calorie and low-calorie. The high-calorie component has values of 16-18 MJ/kg and may be used in energy and thermal recovery processes. The low-calorie component has a value of 8-10 MJ/kg. This may be burned in conventional incinerators. Both of the components can be baled until required. Ferrous materials can also be extracted for recycling.

Dry stabilisation for energy and material recovery processes
In this approach, potentially harmful materials such as batteries are removed, useful materials such as glass, stone, sand and metals are separated for recycling, and the dry-stabilate product can be used as fuel. As inert contaminants do not add to the calorific value of the material, their removal by screening results in an increase in the calorific value of the remaining material to 16-20 MJ/kg. This screening process reduces the weight of the input material by 20%. When the 30% mass reduction during composting is taken into account there is a combined reduction of material of 50%. In addition, there is also an 80% reduction in the amount of ash produced after burning.

11. CENTRALISED COMPOSTING IN THE UK

There has been a considerable increase in composting activity in the UK in recent years (Wheeler 1993, Department of the Environment 1994e, Dixon 1995, Dixon 1995a, Walker 1996a, Anon 1997, Border 1997a, Dampney 1997, Gale 1997, Holland 1997, Moor 1997, Walker 1997, Anon 1998c, Holland and Proffitt 1998, Composting Association 1999d).

A major reason for this increase has been the many changes in relevant waste-related legislation produced by the UK Government and the EU. Several guides are available that explain the legislation and other related legislation in detail, (Waite 1994, Ball and Bell 1995, Department of the Environment 1995c, Garner et al. 1995, Hawke 1995, Lane and Peto 1995, Leeson 1995, Doolittle 1996, NSCA 1996, Anon 1997y, Anon 1997z, Anon 1998h, O'Keeffe 1998)

In the 1995 White Paper Making Waste Work (Department of the Environment 1995a) a target was set for the composting of one million tonnes of the organic component of household waste collected in England and Wales by 2001. In waste strategy 2000 later document by the Department of the Environment, Transport and the Regions (2000) the following targets were proposed for the recovery of value from municipal waste (MSW):

- To recycle or compost 30% of household waste by 2010
- To recycle or compost 50% of household waste by 2015

In 1999 the EU Landfill Directive (European Union 1999) was adopted and came into force. This has to be integrated into UK law by 2001. The Directive requires that all waste must be pre-treated before being landfilled. The Directive further states that the amount of biodegradable municipal waste landfilled must be reduced as follows (allowing for the UN's 4 year derogation):

- 75% of 1995 production by 2010
- 50% of 1995 production by 2013
- 35% of 1995 production by 2020

Estimates suggest that by 2010 some 4.9 million tonnes of biodegradable wastes suitable for composting will have to be diverted from landfill. This figure will increase to 7.3 million tonnes by 2013 and to 10.6 million tonnes of by 2020.

A proposal for a composting Directive is also under consideration by the EU. The proposal is by no means finalised but if eventually adopted it may have a significant effect upon the size of the UK composting industry and the way in which composting is carried out.

11.2 Composting facilities in the UK

In a recent survey (Composting Association 1999d), it was stated that in 1998 in the UK, there were 84 operators running 89 composting sites. These composted a total of 910,821 tonnes of organic waste. Of the 89 sites, 59 were centralised composting facilities composting 835,040 tonnes (92% of waste composted), 11 were community sites composting 939 tonnes (<1% of waste composted), 9 were on-farm sites composting 68,990 tonnes (8% of waste composted), and 9 were on-site facilities composting 5,837 tonnes (<1% of waste composted). The Association's earlier survey in 1997 indicated that 313,215 tonnes of waste were composted in total at 47 centralised composting facilities.

This survey also indicated that 53 of the centralised sites (96% of waste processed) used open air windrows, 2 (3% of waste processed) were in-vessel, and 4 (1% of waste processed) were covered windrow. There were no aerated static pile systems identified in the survey. Three of the centralised sites were said to have a throughput of >50,000 tap, 34 had a throughput of <5,000 tpa and the remainder had throughputs of intermediate size. The reader is referred to this survey for more details of composting facilities in the UK.

The survey indicated that 69% of the waste composted in 1998, at all types of composting sites, was from municipal solid waste. 58% of this was seperated waste from civic amenity sites, 34% was green waste from local authority parks and gardens, 7% from kerbside collections, and 1% was other household waste. The remaining 31% of the total waste composted consisted of 52% from industrial processes, 34% from un-specified commercial processes, and 14% was green waste from landscaping activities.

11.3 Contained composting facilities in the UK

As indicated in the Composting Association survey (1999) there were very few contained composting facilities in the UK, almost all of the others use some form of windrow composting. The following contained facilities are operational:

11.3.1 Gicom fixed batch containers

One of the largest contained composting facility in the UK is that run by CDV, a joint venture company between Anglian Water Services and Ipswich Borough Council (Anon 1996c, Gale 1996, Kaye 1996, Anon 1997t, Barnes 1997, DTI 1997, Hayes 1998). This is based at the Ipswich Water Treatment Works (Figure 11-1).

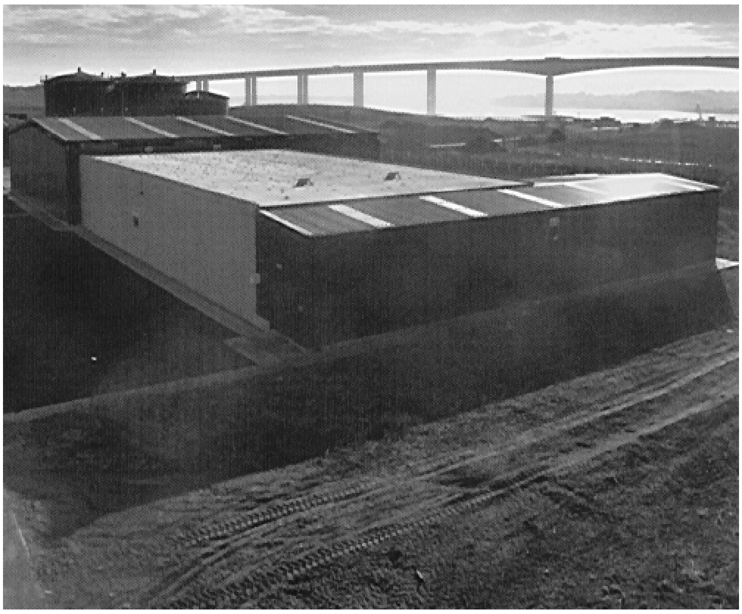

Figure 11-1: CDV batch tunnel composting plant at Ipswich, UK

This site uses a standard 3-tunnel Gicom composting system to compost mixtures of shredded green waste and biosolids. The annual throughput is in the order of 14,000 tpa. An external open biofilter is used in combination with a water scrubber to remove ammonia and any odours produced by the composting process (Figure 11-2).

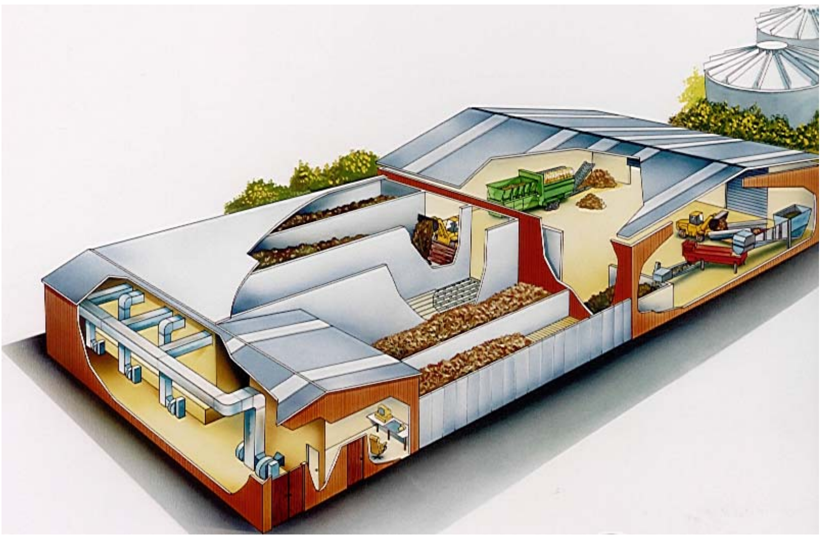

Figure 11-2: CDV batch composting plant at Ipswich, UK – schematic of system

11.3.2 Alpheco modular batch containers

A three unit Alpheco container systems is currently on trial with a UK water company.

11.3.3 Wright Environmental continuous horizontal flow system

A Wright Environmental continuous composting plant is currently being operated on the Isle of Wight.

11.3.4 Waste Mechanics modular batch containers

A two-unit Sirocco container is currently on trial with a UK water company.

11.3.5 Plus Grow Environmental

An agitated bay system in on trial at Blackpool.

12 COMPOSTING IN EUROPE

12.1 Composting in European countries

A number of recent reviews have been written on the development of composting in Europe (Kulik 1996, Rogalski 1996, DHV 1997, Barth and Kroeger 1998, De Bertolid 1998). The following commentry on activities in individual European countries is supported by other references elsewhere in this report.

Austria
In Austria the separation of the organic fraction of household waste is compulsory, (Anon 1995b). Organic material in residual MSW has to be processed before landfilling if the organic matter content exceeds 5%. The O-NORM S 2200 standard is used to control the quality of compost produced from source separated and green waste, (DHV 1997). Certification is controlled by the O-NORM institute.

In 1994 about 300,000 tonnes of green waste and VFG (vegetable, fruit and garden waste) was home composted, 145,000 tonnes processed in composting plants, 25,000 tonnes communally composted and 30,000 tonnes open, turned windrow composted. One hundred and seven windrow composting plants were functioning, along with 6 tunnel composting sites, and a few other technologies, giving a total of 121 composting facilities (DHV 1997).

See Rogalski and Charlton 1995a, Hauer 1996, Herbst 1996, Anon 1997l, Hayes 1997, Raninger 1997 for articles on composting in Austria.

Belgium
There is no current legislation for the collection and treatment of organic waste from households, except for sewage sludge. The Public Waste Company for Flanders (OVAM) has formed an organisation called VLACO to guarantee the quality of any compost produced and to encourage sales and beneficial uses of waste-derived composts (DHV 1997, VLACO 1998). In Flanders the composting of MSW is not allowed, only VFG and green waste is composted. VFG waste is composted at five in-building facilities using VAM, Buhler and Koch technologies, and one site usimg Herhof boxes.

See De Wilde et al. 1996, Anon 1997e for further articles on composting in Belgium.

Denmark
Waste management is based upon a source-separation approach, with the following separate waste streams being collected: vegetable and fruit waste from households, green waste from gardens and parks, and waste food from canteens and restaurants. The collected waste is processed by composting or anaerobic digestion. The Ministry of the Environment issues general guidelines for the required standards of compost to be used in agriculture (DHV 1997). In 1995, 136 composting plants were in operation. Of these, at least 112 were windrow composting plants, with the remainder using several different technologies.

See Jespersen 1992, Hoffman et al. 1995, Rogalski and Charlton 1995b, Carlsboek and Reeh 1996, Hedegaard 1996, Kristensen 1996, Nilsson 1996, Reeh 1996, Anon 1997n, Anon 1997o for other articles in composting in Denmark.

Finland
Organic waste is increasingly collected and processed separately from other wastes. It is intended to increase the number of plants processing organic waste from the current level of 15 to 40-50 by the year 2005. Most of the composting plants are of the windrow type. Standards for waste-derived composts are determine by the Ministry of Agriculture and Forestry.

See Rogalski and Charlton 1995c, Hanninen 1996, Makela-Kurtto et al. 1996, Anon 1997s, DHV 1997 for other articles on composting in Finland.

France
Most attention has been given to the collection and composting of MSW rather than separately collected organic waste streams. Standards exist for the use of waste-derived composts as soil improvers. Of the 352 composting plants operating, 12 use rotating drums, 34 use boxes, 10 use tunnels, 6 use stacked bricks and the rest use windrows.

See Rogalski and Charlton 1995d, Jomier et al. 1996, Merillot 1996, Anon 1997f, DHV 1997 for other articles on composting in France.

Germany
There is a policy at a federal level to offer every household the opportunity for the separate collection of organic waste. All green waste is collected separately. Detailed quality requirements are laid down in the LAGA information sheet M10, (DHV 1997, LAGA 1997). Quality specifications have also been prepared by the Bundesgutegemeinschaft Kompost e.V. (German Federal Composting Quality Assurance Organisation). These standards are registered with the German Institute for Quality Assurance and Marketing (RAL). The RAL-GZ 25 label identifies compost of quality within the required standard. The Federal Compost Quality Assurance Organisation (FCQAO) also has produced standards for the external monitoring of compost facilities and composts (DHV 1997).

Most of the biological treatment of organic wastes in Germany is carried out by composting.

Table 12-1 indicates the range of in-vessel composting systems currently in use in Germany:

Table 12-1: In-vessel composting plants in Germany
(modified from Wiemer and Kern 1997a)

Composting Technology	System Producer
Drum Composting	
Alvahum drum system	Altvater, Herford
Envital drum system	Envital Kompostierungssysteme Vertriebs, Aschaffenburg
Lescha drum system	Lescha-Recycling, Gersthofen
Box (container) composting	
Herhof system	Herhof-Umwelttechnik, Solms
Bio-container system	ML Enstsorgungs- u. Energieanlagen, Ratingen
Compac- box system	MBU Maschinenbau, Ulm, Beimerstetten
Decomposition-filter system	Innmovative Umwelttechnik, Seebenstein
Thoni compact system	Thoni Umwelttechnik, Wangen/Neuravensburg
Agitated bay composting	
Wendelin system	Buhler, Braunschweig
Bio-processing system	Bodenokologisches labor Bremen (BOL), Bremen
Dynacomp system	Thyssen Still Otto Anlagentechnik, Bochum (*)
Koch-AE & E system	Koch Transporttechnik, Wadgassen/Saar
Sorain Cecchini system	Hutec Holzmann Umweltteccnik
Tunnel composting	
Passavant-Schonmackers system	Passavant-Weke, Aarbergen
Gicom system	Gicom, b.v., Biddinghuizen, (Netherlands)
BAS system	AE & E SGP/Waagner Biro Vienna, (Austria)
DBA system	Deutsche Babcock Anlagen, Oberhausen
Bioferm system	Compotec, Ganderkesse (*)
Brick composting	
Brikollare system	Rethmann, Seim
Tower composting	
Decomposition tower system	Steinmuller, Gummersbach

(*) no longer active

In 1994, when 47 intensive composting plants were in operation, the box composting system (Herhof) with 16 plants, was the most commonly used composting system in Germany, with a market share, in terms of numbers of plants, of 34%. This was followed by the ML (5 plants), Buhler (4 plants), Thyssen (4 plants) and Altvar (4 plants) systems, or 11%, 9%, 9%, and 9% of the market respectively. A number of other systems make up the remaining 30% of the market. In terms of throughput of composting feedstock during the same period, which totalled 619,000 tpa, the Buhler plants was the highest (21%), followed by Herhof (18%), Thyssen (14%) and Rethmann (14%).

See Brinton 1992, Bidlingmaier 1993, Manios and Dialynas 1997, Kolb 1996, Wiemer and Kern 1996, Anon 1997b, Anon 1997m, DHV 1997, Gruneklee 1997, Koller and Thran 1997, Wiemer and Kern 1997, Wiemer and Kern 1997a, Anon 1998o.

Greece

There is no national policy for the collection and processing of organic waste.

See Anon 1997h, DHV 1997, Willis et al. 1997 for articles on composting in Greece.

Ireland
The Department of the Environment encourages the diversion of organic wastes into a composting option.

See Anon 1997u, DHV 1997, van der Werf 1998 for articles on composting in Ireland.

Italy There is a policy to separately collect and process household organic waste. There are national standards for composts derived from MSW, and from separately collected organic waste streams (DHV 1997). A total of 42 composting plants are active (Anon 1997i).

See Rogalski and Charlton 1995e, Conti et al. 1996, Giunchi et al. 1996, Schonafinger 1996, Zorzi et al. 1996, Anon 1997i, DHV 1997, Saetti 1998, Zorzi et al. 1998 for further articles on composting in Italy.

Luxemburg
The organic waste component of MSW has to be collected and processed separately. The Environment Agency is producing standards for waste-derived composts.

See Anon 1997d, DHV 1997 for articles on composting in Luxembourg.

Netherlands
The national policy is to recycle as much of the organic component of MSW and green waste as possible by both composting and anaerobic digestion. Direct conversion to energy is also allowed for contaminated feedstocks. Landfilling green waste or the organic component of MSW, is not allowed. Standards are set for compost made from green waste, (VFG waste), and composts have to be certificated to this standard to be sold as VFG-compost, (DHV 1997).

See Oorthuys and Koning 1992, Van der Knijff et al. 1993, Oorthuys et al. 1994, Scharff and Oorthuys 1994a, De Feyter 1995, Rogalski and Charlton 1995f, Oorthuys and Scharff 1996, Anon 1997c, DHV 1997 for other articles on composting in the Netherlands.

Norway
See Rogalski and Charlton 1995g, Anon 1997p, Anon 1997q, DHV 1997, Tronstad 1997 for articles on composting in Norway.

Portugal
In 1994 about 12% of MSW was composted. It is intended to increase this to 15% by the year 2000.
See Anon 1997k, DHV 1997 for articles on composting in Portugal.

Spain
There is no legislation for the separate collection and processing of the organic component of MSW. Standards are set for waste-derived composts (DHV 1997).

See Canet and Pomares 1995, Rogalski and Charlton 1995h, Anon 1997j, DHV 1997 for articles on composting in Spain.

Sweden

The policy is to collect separately the different components of household waste. It is intended that organic waste will not be landfilled after 2005. There are no national standards for waste-derived composts.

See Anon 1997r, Dalemo and Oostra 1997, DHV 1997 for articles on composting in Sweden.

Switzerland
See Brinton 1993, Edelmann 1995, Anon 1997g, DHV 1997 for articles on composting in Switzerland.

12.2 Composting in non-European countries

The following articles give an indication of recent composting activities in the relevant countries: Australia (Block 1997, Anon 1998m, Rochfort 1998), Brazil (Neto 1996), Canada (Gies 1996a, Cave 1997, Gies 1997), Egypt (Steiner and Partle 1997), Ghana (Asomani-Boateng 1996), Indonesia (Perla 1997), Iran (Steiner and Partle 1997), Israel (Chefetz et al. 1996, Levanon and Danai 1997), Japan (Anon 1996d, Shoda 1996), Kuwait (Steiner and Partle 1997), Mexico (del Carpio 1997), Oman (Steiner and Partle 1997), Poland (Biala and Turk 1997), Qatar (Steiner and Partle 1997), Saudi Arabia (Steiner and Partle 1997), Syria (Steiner and Partle 1997), United Arab Emirates (Steiner and Partle 1997), USA (Barkdoll 1991, Curtis et al. 1991, EPA 1991, Blackwell and Neering 1992, EPA 1992, Slivak 1992a, Turner 1992, Anon 1993, Fabian et al. 1993, Kashmanian 1993a, Leege 1993, EPA 1993, EPA 1993a, EPA 1993b, EPA 1993c, EPA 1994, EPA 1994a, Gamelsky 1994, Outerbridge 1994, Renkow et al. 1994, Goldstein and Steuteville 1995, Steuteville 1995, Steuteville 1995a, Egerth 1996, EPA 1996, Goldstein 1996, Goldstein 1996b, Goldstein and Steuteville 1996, Goldstein et al. 1996, Kunzler and Farrell 1996, Steuteville 1996, Steuteville 1996a, Tyler 1996, Border 1997, EPA 1997a, EPA 1997c, EPA 1997d, Goldstein 1997, Goldstein and Block 1997, Goldstein and Glenn 1997, Powell 1997, SWANA 1997, SWANA 1997a, Glenn 1998, Washington State 1998).

13 COMPOSTING FACILITY PROBLEMS AND SOLUTIONS

Although composting is a well-established and rapidly expanding means of recovering organic waste, like any waste management option, it can cause a number of problems, sometimes resulting in the temporary or even permanent closure of the composting facility. No matter which composting technology is chosen, there are lessons to be learned from the economic or technical the problems that have occurred in the past. These problems are discussed below.

Composting facilities, especially contained systems, can only operate economically if they function at or near maximum design capacity. It is therefore essential that sufficient waste is secured for this to happen.

The second major reason for economic failure is the inability to obtain an income from the sale of compost product, or even to give the product away at zero cost. The perceived value of the end product depends upon many factors including: its quality in comparison with competing products, proximity to customers, the marketing skills of the composters, and, of course, cost. The perceived value of waste-derived composts in the UK is low, and most composters rely upon the gate fee as the major source of income.

Technical problems can relate to the efficiency of the composting process and to the containment of factor odours, bioaerosols, leachate, as well as continuous noise and traffic movements.

Although there are relatively few basic methods of composting, there is a very large number of variations of each of these methods commercially available. Many of these have arisen in recent years reflecting the rapid rate of growth of the composting industry and demands for greater protection of the environment from the composting process. As a result, many of the technologies currently available have a limited track record. Great care has to be taken by the prospective composter to ensure that a composting technology has been shown to work, in a cost effective way, under realistic conditions over a significant period of time.

In some cases, the failure is associated with a lack of understanding of the basic principles of composting, or the quality control that is required to produce a useful end product (Eweson 1998). Unless the composting system adopted provides the correct environment for the composting microorganisms at each stage of the process, composting will be slow, unfinished or otherwise unacceptable. The use of inadequately separated feedstock, or inefficient separating equipment, can result in the compost produced being unusable due to of contamination with plastics, broken glass organic residues, pathogens or heavy metals.

Most of the technologies claim to have solved problems associated with the production of odours, bioaerosols, and leachates. In some cases, this is simply not true and problems occur, especially with odours, which are expensive or impossible to rectify.

Other reasons for failure relate not to the technology itself but to the location of the site. Odour only becomes a major problem if there are people in the area to find it objectionable. If a composting site is located close to residential buildings, complaints about odour are almost inevitable no matter what the technology. Odour problems and methods of dealing with them are covered in the next section. Traffic movements and noise associated with composting are also almost guaranteed to result in complaints if the site is badly positioned.

13.1 Overcoming problems by good composting practice

An examination of the above reasons for failure provide the basis of a system of good composting practice which should be read in parallel with the earlier section on optimising the composting process.

13.1.1 The quality of the feedstock must be guaranteed

The feedstock used to make compost must be either inherently clean, source-separated by the householder, or effectively mechanically separated to a degree that allows the production of an acceptable end product. Magnetic separation of all mechanically treated feedstocks should be carried out to remove ferrous and non-ferrous components. An adequate compositional analysis of the waste must be carried out to provide up to date information on the composition and variability of potential feedstock.

In composting schemes that use source-separated household waste it is common to issue a leaflet to householders to indicate which materials are acceptable for composting and which are not. A typical list of acceptable items is found in the Table 13-1.

Table 13-1: Acceptable source-separated household waste

Waste category	Wastes
Kitchen waste	Fruit, salads, vegetable peelings, tea, teabags, coffee grounds and filters, egg shells, stale bread.
Garden waste	Leaves, bark, hedge clippings, twigs, grass clippings, cut flowers
Other waste	Hair, feathers, pet straw, straw, paper, cardboard, sawdust, and wood shavings

Unacceptable components in household waste include:
Plastic bags, other forms of plastic, sacks, foil, ash, vacuum cleaner contents, sweepings, glass, metals, leather, china, stones, batteries, textiles, coloured magazines, wax or waxed packaging, and disposable nappies

Where organic waste is collected in a separate skip at a civic amenity site, a system should be established to encourage the site operator to ensure that contamination of the organic waste is kept to a minimum.

No matter what the source of the waste feedstock, a visual inspection should be made of each batch upon arrival at the composting facility to ensure that quality standards are adhered to and that contamination is within acceptable limits. Provisions should be made for the rejection of batches that do not meet the required standard.

13.1.2 The quantity of the feedstock must be guaranteed

The types and quantities of feedstock needed to allow the composting facility to operate economically must be clearly determined before the commitment to build the facility is made. The required quantities must then be guaranteed. To proceed with a composting development without a guaranteed long-term supply of feedstock would be invite failure.

13.1.3 The required markets and specifications of the end product must be determined

It is essential to determine the markets into which any compost is to be sold before a commitment is made on which composting technology to select. In many cases the possible markets will be limited by the nature and quality of the feedstock. For each of the anticipated markets a compost specification must be recognised. This will include physical, chemical, microbiological, and cost parameters that have to be satisfied have a realistic hope of selling into the market. The ability to produce compost to the required specification using the available feedstock and a selected composting technology must be examined in detail.

13.1.4 The track record of considered composting technologies must be determined

It is essential to obtain detailed technical and financial information on each of the composting technologies being considered. This will include visits to sites currently using the technology and discussions with manufacturers, facility operators, the regulators (both waste permits and nuisance) waste permits and where necessary representatives of local residents. Contact with all of these groups should provide a realistic and honest assessment of the technology.

13.1.5 The selected technology must be versatile enough to handle changes in feedstock type, quantity and seasonality

The exact nature and quantity of feedstock will. change with the time of the year, in the local population and local industry. Changes in legislation may also produce significant changes in both the types of wastes and quantities of wastes available for composting. It is essential that the composting technology chosen must be capable of coping with these changes. For example, the ability for modular expansion in reaction to increased feedstock quantities is desirable.

13.1.6 The composting facility must be properly situated

Many, if not all, of the possible environmental problems associated with composting can be avoided if the facility is located away from potential complainants. A minimum distance of 500 metres or more is often seen as desirable.

13.1.7 Composting- waste treatment or a manufacturing process?

In the UK at the moment, with some important exceptions, the large scale composting of organic wastes is commonly looked upon as a waste management process rather than as a manufacturing process. The income obtained from the sale of compost product is often incidental to the main income obtained from gate fees. This view has a major effect upon every aspect of the way composting is carried out, including the design of the composting site, the selection and quality of feedstock, the composting process itself, and the type of compost produced. In many other countries a more common view is that composting is a manufacturing process that also enables the management of waste to be carried out in a productive and beneficial way. This is also the view taken by the UK mushroom composting industry. If this view is adopted more commonly in the UK there will be major change in the way that compost is made and in the quality and commercial viability of compost products. The work begun by WRAP in late 2001 to develop standards for compost will be a key factor in changing attitudes in the UK.

14 ODOUR PROBLEMS AT COMPOSTING SITES

Offensive odours from composting is one of the greatest environmental problems associated with the industry and is dealt with in some detail below.

The production of offensive odours can cause considerable problems for residents close to composting facilities, (Fischer 1996, Kelsey and Singletary 1996, Pick 1996, Williams 1996, Glenn 1997, Department of the Environment 1997, Wheeler 1997). The extent to which problematic odours are associated with the composting process will depend upon a complex combination of factors. The generation of an odour may not, in itself, be a problem in that in many cases the odour is not released to the environment. If it is released, it may be below the minimal level of detection. The nature of composting odours.

Odours from composting may be released from feedstock components, recirculated water, or the composting process itself. A number of different techniques such as chemical analysis (Burmeister et al. 1992, Day et al. 1998), and olfactory panels (Bliss et al. 1996) are used to detect, analyse, and quantify odours.

A number of specific chemicals from composting systems have been identified as causing offensive odours in composting systems, (Miller and Macauley 1988, Miller 1991a, Henz et al. 1992, Kissel et al. 1992). Some of these are listed in Table.14-1.

Table 14-1: Selected odoriferous compounds associated with composting (modified from Miller (1991a))

Category of compound	Specific compound	Characteristic odour
Sulphur compounds	hydrogen sulphide	rotten eggs
	carbon oxysulphide	pungent
	dimethyl sulphide	foul
	carbon disulphide	foul
Nitrogen compounds	ammonia	pungent
	trimethyl amine	pungent
Organic acids	ethanoic	vinegar
	propanoic	rancid
	butanoic	rancid
Other	ethanal	pungent
	3-methylindole	faecal

It is very difficult to identify individual compounds such as those above by smell alone and chemical analysis is needed. Furthermore, mixtures of different compounds produce new odours, (Summer 1971). Not all of these chemicals are produced in every composting operation. Even if they are produced it may well be below the level which causes environmental problems.

The odour thresholds of these compounds vary. Of the chemicals listed above, ammonia has the highest threshold at 37 ppb (parts per billion), while 3-methylindole has the lowest at 7.5×10^{-5} ppb.

Brinton (1998) has looked in detail at the production of volatile organic acids (VOAs) in fresh and composted material. VOAs have a significant potential to produce odour problems both before and during composting. Brinton found considerable variation in VOA levels in the 712 compost samples studied, ranging from 75 to 51,474 parts per million on a dry basis. VOA levels are also important in determining the phytotoxic properties of composts, (Manios et al. 1989). No guidelines currently exist for maximum VOA levels in composts.

14.1 Potential sources of odour generation in the composting process

Odours may be released during the manufacture of compost from a number of sources (Anon 1994, Mahin 1995, Bidlingmaier 1996, Hentz et al. 1996, Anon 1997a, Caballero et al. 1997, Roberts and Sellwood 1997, Smalley 1998, Miller 1993). The feedstock may often generate offensive odours, especially if it is stored for some time prior to treatment. Even fresh feedstock may produce odours during the shredding or mixing stages, which can generate aerosols. Part of the overall quality control process adopted by the composting facility should cover the receipt, storage and treatment of the feedstock used. Some feedstocks, such as green waste, have a fairly low potential for odour generation if handled and stored correctly. Other feedstocks or additions such as sewage sludge and source-separated household waste, have a much higher potential for odour generation.

There are significant advantages in receiving, storing and handling all types of feedstock in an enclosed environment. Many of the in-vessel composting systems described in this report take place within a building under negative pressure to prevent the release of odours outside the facility. This also prevents the feedstock from becoming too wet.

All composting processes involve the production of leachate. This is often high in dissolved nitrogenous and sulphurous material and can be a major source of odour production. In systems where this leachate is allowed to accumulate in significant quantities, often stored in non-aerated tanks or pits, the subsequent movement of this water can release significant quantities of odours. If the water is allowed to become anaerobic and sprayed on the feedstock it can be a major source of odours sprayed on to the feedstock (Urone 1976).

Recirculated water is not always the main source of odours, and the pattern of odour distribution will vary from site to site. The composting process itself can produce odours. Some studies indicate that the windrows form the main source of odours (Gerrits 1994), as shown in the Table.14-2.

Table 14-2: Production of volatile sulphur compounds during composting
(Modified from Gerrits, 1994)
(Data in mmol/tonne compost fresh wt.)

Compound	Pre-wet heap	Windrows	Phase II tunnels
Hydrogen sulphide	0.6	22.3	0
Carbonyl sulphide	2.3	21.7	3.2
Methanethiol	2.3	30.0	0.6
Dimethylsulphide	16.4	25.4	10.2
Carbon disulphide	3.7	27.2	2.4
Dimethyl disulphide	1.9	28.3	0.5
Dimethyl trisulphide	1.7	2.4	1.1
Total sulphur	37.9	217.6	23.0

If the composting process becomes anaerobic, through waterlogging, lack of air eg through insufficient turning or incorrect structure, or by some other means, high concentrations of a range of volatile fatty acids such as acetic acid, propionic acid and butanoic acids can be formed (Lynch et al. 1980). These have a characteristic rancid smell.

Sources of sulphur within the composting mixture can, under anaerobic conditions, be reduced to hydrogen sulphide producing a 'rotten egg' smell (Derikx et al. 1990, Derikx et al. 1991). The sulphur-containing amino acids in chicken litter and other nitrogenous wastes (methionine and cystine) can cause problems (Overcash et al. 1983). Methionine can break down into methanethiol producing the smell of rotten cabbage (Banwart and Bremner 1975). Although cystine can also form volatile sulphur compounds it is much less likely to be problematic than methionine. The production of ammonia is a normal part of the composting process. If excessive quantities of nitrogen-containing chemicals are present, the amount of ammonia generated can be considerable.

14.2 The release of odours in the composting process

The odours associated with the composting process only cause problems if they escape into the surrounding environment and persist there for a significant time, (Walker 1993). Not all odoriferous compounds escape in this way. They may instead be captured on to physical surfaces or into aqueous solution, or become broken down into non-odorous compounds by further microbiological or chemical reaction.

The volatile fatty acids that may be produced are highly soluble in water and are readily metabolised to carbon dioxide under aerobic conditions. Ammonia is much more of a problem, in that it persists in the atmosphere for about 7 days (Urone 1976). Once released into the environment it is only dissipated by diffusion or by precipitation.

The volatile sulphur compounds that may be produced during composting are only slightly soluble in water and vary greatly in terms of their atmospheric residence times. For example, hydrogen sulphide has an estimated residence time of one day while methanethiol lasts for only 4 to 5 hours (Urone and Schroeder 1978). If hydrogen sulphide is produced within an anaerobic section of a windrow it can be very rapidly oxidised upon coming into contact with an aerobic section of the compost and not released into the atmosphere. Thiols and organic sulphides are also rapidly precipitated on contact with oxygen.

14.3 The treatment and prevention of odours in composting

As stated previously, there are three main activities in a composting facility which can produce odours:

- the receipt and storage of raw materials;
- leachate and recycled water; and
- the composting process itself.

The first stage of any odour management study is to determine which, if any, of these activities is the cause of odour production. The second stage is to decide if the task is to treat the odours produced, to prevent their formation in the first place, or to use a combination of both techniques.

14.3.1 Odour treatment

This normally involves a chemical and/or physical approach by the use of wet scrubbers, air filters, biofilters (Dunson 1993, Heining et al. 1995) or chemical masking agents (Composting Association 1999a). Much information is already known about the solubility, vapour pressure and reactivity of the chemicals likely to cause problems. This information can be used to predict the most effective treatment to use.

The first stage of any odour treatment process is to contain the air that may become contaminated with the odour-producing chemicals. This often involves the carrying out of processes within a building. The act of containing material in this simple way may be sufficient to reduce odour problems to acceptable levels. As an additional step, the air within the building can be taken through some form of ventilation system for treatment to remove odours. A minimum amount of air exchange within the building must occur to protect the workforce.

Treatment of odours may not be a simple matter because of the high volatilities and low aqueous solubilities of many odour-producing compounds. For these reasons the effectiveness of water spray systems or wetted filter systems may be limited. Chemical methods, such as a scrubbing system, can be effective although sometimes very expensive. Sulphuric acid can be used to remove ammonia fumes, and sodium hypochloride to oxidise sulphur compounds. This method of treatment can be very expensive. The composting technology chosen, whether open (Bernal et al. 1996), or contained, can have a major effect upon the extent of this problem. It is possible to recycle the nitrogen-containing water from a scrubbing system back into the composting operation, (Gerrits and Amsing 1997).

Biofilters made from compost, bark, soil and other materials can also be used to remove odours from contaminated air. The high level of microbial activity within biofilters is used to trap and break down odour producing chemicals. The use of biofilters is considered in greater detail later in this report.

14.3.2 Odour prevention

This approach avoid the creation of the odorous compounds by carefully controlling the initial feedstock mixture and the microbial ecology in which composting occurs. This may be a more complicated solution than odour treatment but is often more economical.

If the proportions or the quantity of the various components that comprise the composting feedstock are allowed to vary, there may be a misbalance of the nutrients present. It is therefore vital that a very tight control is kept over the quality of the feedstock and the initial feedstock formulation.

The microbial ecology of a composting system is very complex and not fully understood. However, it is possible to influence the biochemistry of the composting process, and hence the production of odour-producing chemicals, by changing the physical and chemical environment in which the composting micro-organisms operate. Ensuring that the composting process is kept aerobic will make a major contribution towards preventing the formation of odorous chemicals such as hydrogen sulphide. This is probably the most important single step that an operator can take to prevent odour problems. A number of additives have been tried in attempts to reduce odour production in the manufacture of compost (Anon. 1994). Several commercial companies offer products based on a variety of micro-organisms are claimed to reduce or remove odours produced by the composting process. Much work needs to be carried out to prove the cost effectiveness of this approach to odour control.

It is sometimes necessary to carry out one or more major retrofits of a composting facility in order to remove offensive odours. An example of this situation is reported in Alix (1998). In the composting site in question, sewage sludge was originally (1983) composted in eight, open-topped concrete bunkers, aerated by fans on a 30 minute cycle. There was no odour treatment process. As a result of odour problems, the composting bunkers were totally enclosed (1991), a biofilter was built, the feedstock ratio of sewage sludge to wood chip amendment was changed, the composting pile height was lowered, and the 30 minute aeration cycle was reduced to 15 minutes. Some years later (1997), the odour problems returned and a second retrofit took place. This time new, totally enclosed concrete bunkers were built, each aerated independently under computer control, and all process air was taken through a new biofilter. Along with other changes, this resulted in the removal of the odour problems. The above is a good example of how the understanding of odour problems, and the methods to solve them, has increased in the last few years.

In the UK, a Secretary of State's Guidance Note has been issued for the production of compost from straw and animal manures for the commercial growing of the white mushroom, Agaricus bisporus (DoE 1997). This potential problems with odour production and has the aim that all emissions of air are free from offensive odour outside the process boundary.

The following points of guidance, amongst others, are made with particular reference to the early stages of mixing and wetting the feedstocks, and the outdoor windrow stage of making the mushroom compost:

All potentially malodorous liquids, such as leachate arising from composting operations, should be stored in tanks or lagoons, designed and situated to minimise the impact of any odour which is generated.

All potentially malodorous raw materials which are intended to be delivered to the processing site and which are so wet as to be likely to give rise to offensive odour during storage prior to use, should not be accepted at the processing site.

All potentially malodorous solid raw material should be stored so as to prevent them becoming so wet as to give rise to offensive odours – for example, by sheeting the material or by the provision of covered storage areas. The size of the stockpiles should be kept to a minimum and all potentially malodorous raw materials should be used as soon as possible after delivery to the site.

The composting operation should be carried out in such a way as to covers ensure that organic decomposition proceeds aerobically. This will involve optimising the penetration of air into the decomposing material at all times. Additionally, the substrate should be turned regularly and as often as is necessary to prevent as far as possible the development of malodorous anaerobic breakdown conditions. This will normally entail turning the substrate at least once in every three days.

Liquid storage tanks which contain leachate arising from the decomposition of the substrate should be aerated to prevent malodorous anaerobic conditions developing in the liquid.

The use of odour masking agents and counteractants should not be permitted except in the case of counteractants where their use is the only practicable means of achieving a satisfactory level of odour.

In the case of new or substantially rebuilt processes, or processes in particularly sensitive locations, consideration should be given to the use of one of the innovative composting technologies which are currently being investigated (aerated feedstock heaps, aerated feedstock in tunnels, aerated windrows, aerated compost tunnels, use of custom built windrow turners).

Staff at all levels should receive the necessary training and instruction in their duties relating to control of the process and emissions to air.
Most of the principles behind these guidance points are applicable to the composting of MSW and other organic wastes.

14.4 The design construction and use of biofilters

Work has also been carried out on the use of biofilters to treat volatile organic composts (VOCs) and odour-carrying air generated by composting feedstock or the composting process (Kissel et al. 1992, Williams and Miller 1992, Williams and Miller 1993, Wheeler 1994, Conrad 1995, Eitzer 1995, Heining et al. 1995, Goldstein 1996, Finn and Spencer 1997, Toffey 1997, Boyette 1998, Tahraoui and Rho 1998, Goodwin et al. 2000). Some of these studies have taken place with laboratory scale systems (Rho et al. 1995, Tahraoui et al. 1995, Tahraoui and Rho 1998). Additional work has also been carried out in other odour-generating industries to make the use of biofilters more effective (Lith et al. 1990, Lesson and Winer 1991, Brenner et al. 1993, Hodge and Devinny 1994, Hodge and Devinny 1995). Biofilters used in the composting industry fall into two main categories: open biofilters and closed biofilters. Most biofilters in the industry, at the moment at least, are of the open type. They are cheaper to construct and maintain than the closed versions but are still very effective. They may be constructed at and below soil level or above ground in some form of container.

Biofilters can be used to treat air taken from in-vessel composting systems or from buildings containing open composting operations or composting feedstocks. The air requiring treatment is normally ducted to the biofilter where it is distributed underneath the biofilter matrix, commonly by a series of perforated pipes, embedded in concrete or laid under gravel. Great care is taken to ensure that no short-cuts develop through the biofilter matrix that might allow untreated air to escape.

The biofilter is filled to a depth of around one metre with composted bark, mature compost, woodchips, soil, peat, heather, or a mixture of these. The selected formulation is mixed by a front-end loader or mixer and moistened to bring the overall moisture to 50-55%. It is normal to allow at least two weeks between constructing a biofilter and expecting it to function efficiently. This is to give time for the required micro-organisms to develop in the matrix .The biofilter matrix material can be expected to last 2-4 years before requiring replacement. It is normally advisable to put down a layer of wood chips or small stones between the biofilter matrix and the floor of the biofilter. This helps to keep the air flow rate at acceptable levels for longer. Even so, it is to be expected that the pressure drop across the biofilter will increase with time as the biofilter matrix slowly degrades. The fan must be sized anticipate this change.

Typical loading rates for the biofilters are in the order of 0.5-1.5 m^3 of treated air per m^2 of biofilter surface. The size and number of biofilters required has to be calculated carefully from a knowledge of the type and volume of wastes to be processed, and the composting technology chosen. Allowance should be made for a possible expansion of the composting facility. In general, terms the total biofilter surface required for a facility will vary with:

- the presence or absence of air pre-treatment (see below);
- the concentration of odorous compounds in the air;
- the biodegradability of these compounds;
- the total volume of air requiring treatment; and
- the standards the treated air must meet.

In the simplest biofilter systems, there is little or no control over the moisture or temperature of the biofilter matrix. In the most sophisticated systems, parameters such as temperature, humidity, and rate of air flow, and air pressure can be monitored and controlled. The hole size in the aeration pipes under the biofilter and the exact distribution of these holes can have a great effect upon the biofilter efficiency. The same principles to ensure an even distribution of air in a biofilter apply to the distribution of air in batch composting tunnels. Excess leachate may drain from the biofilter and be recirculated to the compost operation or be diverted to a water treatment facility.

Biofilters have a tendency to dry out with time unless the air entering the biofilter is saturated (Pinnette et al. 1993). This may be due to unsaturated air entering the biofilter or by loss of water from the matrix caused by elevated biofilter temperatures brought about by microbial activity. Humidification can be accomplished by passing air requiring treatment through water sprays before it enters the biofilter. This technique also cools the air leaving the compost. Unless this cooling takes place, the air may enter the biofilter at too high a temperature for the micro-organisms in the biofilter matrix. A further benefit of this pre-treatment is that air-borne particles such a dust or spores are removed from the air. It is also possible to add water evenly to the top of the biofilter using a series of surface sprays.

The pre-treatment process may also involve reducing or removing any ammonia in the compost exhaust gases. This can be accomplished by passing the exhaust air through a water spray or through an acid treatment facility. Simple water scrubbing can remove up to 70% of the ammonia present, while acid treatment can remove up to 95%. Much smaller quantities of water are required for treatment using an acid wash facility.

It is important that biofilters are constructed in such a way that repairs can be carried out, or the biofilter matrix replaced, without the ability to treat the air being compromised. This often involves building biofilters with two or more cells to allow one cell to be taken out of commission for repair. A valve system is required to redirect the air as required. There may also be additional fans installed to ensure that fan failure does not prevent the biofilter from operating.

Problems with biofilters, assuming they are correctly designed in the first place, tend to be caused by air bypassing the biofilter matrix through cracks, by air being unevenly distributed across the base of the biofilter, and by the matrix drying out. Care should be taken in ensuring that the matrix does not shrink away from the retaining walls. It is important to check regularly the performance of the biofilter in a quantifiable way and not just rely upon the subjective test of whether odour can be detected or not (Amihron and Kuter 1994). The pressure drop across the biofilter, the rate of air flow into the biofilter (compared to design specifications), and the matrix temperature and moisture content should be recorded on a regular, probably weekly, basis. Temperatures should not be allowed to rise above 35-40°C.

14.4.1 Open biofilters

These are the commonest form of biofilters and consist of large rectangular concrete bays with retaining walls 2-3 metres deep and as large as the volume and loading of the air needing treatment requires. The floor of the bay contains perforated pipes linked to fans that extract the odour-carrying air from the composting process area. The bays are filled with composted bark, mature compost, woodchips, soil, peat, heather, or mixtures of these.

14.4.2 Modular biofilters

A number of companies are now producing biofilters based on some form of container. These have the advantage of not drying out so quickly and offer the opportunity for some form of environmental control to make the biofilters more efficient.

BEV (Germany)
The BEV modular biofilter (Figure 16-1) is based on a simple container that can be connected to the air outlet of the composting facility.

15 MECHANICAL-BIOLOGICAL TREATMENT OF WASTES PRIOR TO LANDFILL

An increasing amount of work is being carried out on the pre-treatment of municipal solid wastes, and similar wastes, prior to their being landfilled. The publication of the Landfill Directive (EU 1999) has focussed attention on this use of composting and other processes.

In Germany, residual wastes, after recycling or reuse, have to be pre-treated before landfill to reduce deleterious effects such as the production of landfill gas, leachates and landfill settling. This activity is determined by the Technische Anleitung Siedlungsabfall, (Anon 1993a) which sets standards for landfill sites and the minimum pre-treatment of wastes prior to landfill. Only waste with a volatile solids of <5% can be deposited. There are at least 20 facilities in Germany that are carrying out mechanical-biological treatment MBT) of over one million tonnes of wastes. These processes typically reduce the volatile solids content to between 15-30%. Soyez et al. (1999) determined a set of parameters for wastes processed in this way based upon the respiration coefficient and anaerobic gas production. They found that MBT could produce material with a respiration coefficient of 5 mg/g dm^3 or lower and a gas production of 20 l/kg dm^3 or lower within 8-28 weeks depending upon the exact method used. These values corresponded with an 'ecologically tolerable level of gas production within the landfill'.

Paar et al. (1999) has looked at the role of simple windrow composting in the pre-treatment of municipal solid wastes prior to landfilling. He proposes a number of possible scenarios in which windrow composting can be effectively used following either contained composting for 7-14 days, composting using the Brikollare method for 4-6 weeks (see Section 12.3.20), or semi-open methods for 4-12 weeks. The non-turned windrow system proposed has a passive aeration system (dome aeration), using natural convection currents to aerate the composting waste through a series of aeration channels, and is built on top of the landfill site.

In Austria, the Austrian Landfill Regulation (Austrian Federal Ministry for Environment, 1996) accepts the use of MBT processes for the pre-treatment of organic wastes prior to landfill. After 2004, the main criterion to control the landfilling of pre-treated organic wastes is that there will be an upper limit of a gross calorific value of 6,000 kJ kg^{-1} TS. In this context, Raninger et al. (1999) looked at optimising the co-composting process at the ZEMKA facility in Zell am See, Austria, that processes 20,000 tonnes of MSW and 5,000 tonnes of biosolids a year. This process uses a rotating drum followed by an induced aerated static pile system and a maturation stage. The changes in the process resulted in a compost end product, after 16 weeks maturation, that had a gross calorific value of 5,185 kJ kg^{-1} TS. According to the Austrian standards specific oxygen uptake rates (SOUR), after 4 and 7 days, of 5 and 9 mgO_2 g^{-1} TS respectively are set. Using the system at ZEMKA these limits were reached within 13 weeks of maturatiin. The other Austrian standard for a bio-gas production rate (GPR) of less than 20 N1 kg^{-1} TS was met after 11 weeks of maturation.

Cossu et al. (1999), has examined the various stability standards for pre-treated wastes intended for eventual landfilling and recommends the use of a simple lead acetate paper test for stability.

16 APPENDICES

16.1 References

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16.2 Composting-related associations and information sources

The following Table provides a selection of organisations with useful information on various aspects of composting.

Table 16:1: Composting related associations and information sources

Organisation	Address
Bionet	http://www.bionet.net
Bundesgutegemeinschaft Kompost	Schonhauser Strasse 3, D-50968 Koln, Germany. Tel: +49 221 934 70075, Fax: +49 221 934 70078
Composting Association	Avon House, Tithe Barn Road, Wellingborough, Northamptonshire, NN8 1DH, UK Tel: +44 (0)1933 227 777 Fax: +44 (0) 1933 441 040
Composting Council	114 S. Pitt St., Alexandria, VA 22314, USA, Tel: +1 703 739 2401, Fax: +1 703 739 2407 Internet: http://compostingcouncil.org/index.html
Composting Council of Canada	16 Northumberland, Toronto, Canada, Tel: +1 416 535 0240, Fax: +1 416 536 9892, Internet: http://www.compost.org/
Cornell University	Department of Agricultural & Biological Engineering, New York State College of Agriculture and Life Sciences, Riley Robb Hall Cornell University, Ithaca, NY 14853-5701 Internet: http://www.cfe.cornell.edu/compost/
Degradable Polymers Council (DPC)	Suite 600K, 1801 K Street, NW Washington, DC 20006, USA., Tel: +1 202 974 5200, Fax: +1 202 296 7005, Internet: http://www.degradablepolymers.org
DHV	Laan 1914, No. 35, PO Box 1076, 3800 BB Amersfoort, Netherlands. Tel: +31 33 468 2700, Fax: +31 33 468 2801
FEAD (Federation Europeenne des Actvities du Dechet et de l'Environment – European Federation of Waste Management and Environmental Services),	Avenues des Galois 19, B-1040 Bruxelles, Belgium. Tel: +32 2 732 32 13, Fax: +32 2 734 95 92
Institute of Waste Management	IWM Business Services Ltd., 9 Saxon Court, Northampton, NN1 1SX, UK. Tel: +44 (0)1604 620 426, Fax: +44 (0)1604 604 467
International Biodegradable Products Manufacturing Association (BPMA)	Avenue E. Mounier, 83 Box 1, Brussels, Belgium. Tel: +32 2 772 90 80, Fax: +32 2 772 68 35
International Society for Mushroom Science (ISMS)	196 Rugby Road, Leamington Spa, Warwickshire, CV32 6DU, UK. Tel: +44 (0)1926 882150, Fax: +44 (0)1926 882 150. Internet: http://www.hri.ac.uk/isms/
ISWA (International Solid Waste Association)	General Secretariat, Laederstraede 9, 2 floor, DK-1201, Copenhagen, Denmark, Tel: +45 33 91 44 91, Fax: +45 33 91 91 88.

Organisation	Address
JG Press Inc.	419 State Avenue, Emmaus, Pennsylvania, 18049, USA. Tel: +1 610 967 4135 Fax: +1 610 967 1345
Mushroom Growers Association	Mushroom Growers Association, 2 St. Pauls St., Stamford, Lincs., PE9 2BE, UK. Tel: +44 (0)1780 766 888, Fax: +44 (0)1780 766 558
US Environmental Protection Agency	Ariel Rios Building, 1200 Pennsylvania Avenue, N.W. Washington, DC 20460 Tel: +1 (202) 260-2090 Email: public-access@epamail.epa.gov.
Solid Waste Association of North America (SWANA)	PO Box 7219, Silver Spring, MD 20907-7219, USA. Tel: +1 301 585 2898, Fax: +1 301 589 7068
University of Leeds	Water and Environmental Engineering Group, Dept of Chemical Engineering, Leeds, LS2 9JT, UK. Tel: +44 (0)113 233 2308, Fax: +44 (0)113 233 2243
World Resource Foundation	Bridge House, High St., Tonbridge, Kent, UK. Tel: +44 (0)1732 368 333, Fax: +44 (0)1732 368 337

16.3 European waste management associations

The following table provides contact details for the national members of FEAD.

Table 16:2: European waste management associations

Country	Organisation	Address
Austria	VOEB (Verband Osterreichischer Entsorgungsbetriebe Bundesgeschaftsstelle)	Reisnerstrasse 40, A-1030, Wien, Austria. Tel: +43 1 713 0253, Fax: +43 1 715 2107
Belgium	UGBN/ABSU (Union Generale Belge du Nettoyage et de la Desinfection/Algemene Belgische Schoonmaak-en Ontsmettingsunie)	Avenue des Nerviens 117, B-1040, Bruxelles, Belgium. Tel: +32 2 732 13 42, Fax: +32 2 735 07 87
France	FNADE (Federation Nationale des Activites du Dechet et de l'Environement)	110 Avenue de la Republique, F-75011, Paris, France. Tel: +33 1 4805 9669 Fax: +33 1 4805 9809
Germany	BDE (Bundesverband der Deutschen Entsorgunswirtschaft e.V.)	Haus der Deutschen Entsorgunswirtschaft, Schonhauser Strasse 3, D-50698, Koln, Germany. Tel: +49 221 934 700 00 Fax: +49 221 934 700 90
Italy	FISE (Federazione Impresse di Servize Assoambiente)	Via del Poggio Laurentino 11, I-00144, Roma, Italy. Tel: +39 6 592 10 76, Fax: +39 6 591 99 55
Luxembourg	FLEA (Federation Luxembourgeoise des Enterprises d'Assainissement)	c/o Lamesch – Z.I. Wolser Nord, L-3225, Bettembourg, Luxembourg. Tel: +352 52 27 271, Fax: +352 51 88 01

Country	Organisation	Address
Netherlands	NVGA (Nederlandse Vereniging Verwerkers Gevaarlijk Afval)	Kerkplein 3, NL-4209 AC, Schelluinen, Netherlands. Tel: +31 183 623771, Fax: +31 183 623741
Spain	ASELIP (Associacion de Empresas de Limpleza Publica)	Cristobel Bordiu 55, E-28003, Madrid, Spain. Tel: +34 1 554 47 19, Fax: +34 1 535 33 06
Sweden	RVF (Svenska Renhallingsverks-Foreningen) Internet: http://www.rvf.se/frame_rvfeng.html	Ostergatan 30, S-21122, Malmo, Sweden. Tel: +46 40 35 66 00, Fax: +46 40 971 094
UK	ESA (Environmental Services Association)	154 Buckingham Palace Road, London, SW1W 9TR. Tel: +44 (0)171 824 8882, Fax: +44 (0)171 824 8753

16.4 Composting-related publications

The following are publications that are either dedicated to composting or have a high composting input. Other publications that carry articles on composting can be seen in the References Section of the Appendices.

Table 16:3: Composting-related publications

Organisation	Address
Biocycle	JG Press, 419 State Avenue, Emmaus, PA 18049, USA. Tel: +1 610 967 4135, Fax: +1 610 967 1345, Email: biocycle@jgpresss.com, Internet: http://www.jgpress.com/
Compost Science and Utilization	JG Press, 419 State Avenue, Emmaus, PA 18049, USA. Tel: +1 610 967 4135, Fax: +1 610 967 1345, Email: biocycle@jgpresss.com Internet: http://www.jgpress.com/
Composting News	Avon House, Tithe Barn Road, Wellingborough, Northamptonshire, NN8 1DH, UK Tel: +44 (0)1933 227 777 Fax: +44 (0)1933 441 040
Gardening Which?	Consumers' Association, PO Box 44, Hertford X, SG14 1SH, UK. Tel: +44 (0)645 830 089, Fax: +44 (0)171 830 8585
ISWA Times	ISWA General Secretariat, Laederstraede 9, 1201 Copenhagen K, Denmark. Tel: +45 33 91 44 91 Fax: +45 33 91 91 88
ISWA Yearbook	ISWA General Secretariat, Laederstraede 9, 1201 Copenhagen K, Denmark. Tel: +45 33 91 44 91 Fax: +45 33 91 91 88
Mushroom Journal	Mushroom Growers Association, 2 St. Pauls St., Stamford, Lincs., PE9 2BE, UK. Tel: +44 (0)1780 766 888, Fax: +44 (0)1780 766 558
Warmer Bulletin	World Resource Foundation, Bridge House, High St., Tonbridge, Kent, UK. Tel: +44 (0)1732 368 333, Fax: +44 (0)1732 368 337

Organisation	Address
Waste Management and Research	The Journal of the International Solid Waste Association, (ISWA). Published by: Munksgaard International Publishers Ltd., Periodicals Dept., 35 Norre Sogade, PO Box 2148, DK-1016 Copenhagen K, Denmark, Tel: +45 33 12 70 30, Fax: +45 33 12 93 87, Internet: http://www.munksgaard.dk
Wastes Management	IWM Business Services Ltd., 9 Saxon Court, Northampton, NN1 1SX, UK. Tel: +44 (0)1604 620 426, Fax: +44 (0)1604 604 467

16.5 Commercial composting organisations

The following companies manufacture or supply composting-related equipment and services:

Table 16:4: Manufacturers and suppliers of composting equipment and services

Company	Contact Details	Equipment/Services
Advanced Clean Air Technology	118 Whittesley Rd., Stanground, Peterborough, PE2 8RP, UK Tel: +44 (0)1733 313 688 Fax: +44 (0)1733 313 688	Chemical odour masking sprays
AEA Technology	Biotechnology Dept., Culham, Oxon., UK, OX11 0RA, UK Tel: +44 (0)01235 463 542 Fax: +44 (0)01235 463 030	*Sirocco* modular batch tunnel. *Sirocco* modular biofilter
AEM B.V.	Groesweg 22, 5993 NN Maasbree, The Netherlands. Tel: +31 77 465 2275 Fax: +31 77 465 1957 Email: aem@plex.nl	Batch tunnels
Ag-Bag International	2320 SE Ag-Bag Lane. Warrenton, OR, 97146 USA Tel: +1 503 861 1644 Fax: +1 503 861 2527 Email: compost@ag-bag.com Internet: http://www.agbag.com	Ag-Bag covered windrow system
Air Spectrum Environmental Ltd.	Spectrum House, North St., Droitwich Spa, WR9 8JB, UK Tel: +44 (0)1905 798 000 Fax: +44 (0)1905 798 153 Internet: http://www.airspectrum.com	Chemical odour masking sprays
Alpheco Ltd.	Westhill, Copdock, Ipswich, IP8 3ET, UK. Tel: +44 (0) 1473 730 259 Fax: +44 (0)1473 730 259 Email: alpheco@anglianet.co.uk	Modular batch tunnel
American Biotech Inc.	3223 Harbor Drive, St. Augustine, FL 32095, USA Tel: +1 904 825 1500 Fax: +1 904 825 1524 Email: compost@aug.com Internet: http://www.abt.compost.com	Continuous vertical flow system
Arbor Eater Ltd.	1 Charlewood Place, Charlewood, Surrey, RH6 0EB, UK Tel: +44 (0)1293 862 036 Fax: +44 (0)1293 861 167	Agents for Caravaggi and Pezzolato shredders

Company	Contact Details	Equipment/Services
Augspurger Engineering Inc.	15455 North Greenway-Hayden Loop, Suite C-14, Scottsdale, Arizona, 85260-1609, USA. Tel: +1 602 483 5966 Fax: +1 602 483 0070.	Composter 1 – 2.3 cubic metre batch tunnel. Composter 2 – 7.6 cubic metre continuous tunnel
Austria Energy and Environment	Siemensstrasse 89, A-1211 Wien, PO Box 2, Austria. Tel: +43 1 25045 Fax: +43 1 25045 130 Email: contact@aee.vatech.co.at Internet: http://www.aee.vatech.co.at	Design of composting plants
Bedminster Bioconversion Corporation	145 Church St., Suite 201, Marietta, GA 30060, USA. Tel: +1 770 422 4455 Fax: +1 770 424 8131 Email: billy@bedminster.com Internet: http://www.bedminster.com	Rotating drum composter
BEV Sattler	Heinersdorfer Stasse 17 L, D-04651 Bad Lausick, Germany. Tel: +49 (0)3 43 45 2 51 51 Fax: +49 (0)3 43 45 2 51 53	Modular biofilters
Biocorp	2619 Manhattan Beach Boulevard, Redondo Beach, CA 90278, USA. Tel: +1 888 206 5658 Fax: +1 310 643 1622 Email: info@biocorp.comInternet: http://www.biocorpusa.com	Manufacturer of Mater-Bi biodegradable plastic bags
Bio-Mac Conversions Ltd.	Rt. 1, Box 324, Presque Isle, Maine 04769, USA. Tel: +1 207 764 2901 Fax: +1 207 764 2991	In-vessel composting
Biomax Inc.	764 St-Joseph Est., Suite 124, Quebec City, Quebec, G1K 3C4, Canada. Tel: +1 418 529 2585 Fax: +1 418 529 9413 Internet: http://www.enviroaccess.ca/fiches_4/F4-10-96a.html (CompostAir) http://www.enviroaccess.ca/fiches_4/F4-01-96a.html (Robotcompost)	CompostAir - Aerated static pile Robotcompost – agitated bay
BioPlan A/S	Livovej 21, DK-8800 Viborg, Denmark. Tel: +45 866 13 833 Fax: +45 866 268 36 Email: anneseth@post3.tele.dk	Rectangular agitated bay
Biotal Industrial Products Ltd.	5 Chiltern Close, Cardiff Industrial Park, Cardiff, CF4 5DL, UK. Tel: +44 (0)1222 747 414 Fax: +44 (0)1222 747 140 Email: info@biotal.co.uk Internet: http://www.biotal.co.uk	Composting accelerator
Biotech 2000 Inc.	2 Sylvan Way, Suite 303, Parsippany, NJ 07054, USA. Tel: +1 973 898 1401 Fax: +1 973 898 1403 Email: egarian@erols.com	Batch tunnel
BMB GmbH	Egeiner Strasse 12 39448 Westeregein Germany [See Hoofmark (UK) Ltd.]	Small container system

Company	Contact Details	Equipment/Services
Bol (Bodenokologisches Labor Bremen GmbH)	Wilhelm-Herbst-Strasse 12, 28359 Bremen, Germany. Tel: +49 (0)421 20 10 411 Fax: +49 (0)421 20 10 413 Email: boel-bremen@t-online.de	Agitated bay
Bouldin and Lawson Inc. (Ecology Division)	PO Box 7177, McMinnville, TN 37110-7177, USA. Tel: +1 615 668 4090 Fax: +1 615 668 3209	Two-stage shredder
Brown Bear Corporation	Bluegrass Industrial park, PO Box 29, Corning, Iowa 50841, USA. Tel: +1 515 322 4220 Fax: +1 515 322 3527	Windrow turners
BRV Technologie-Systeme	Postfach 480129, D-48078 Munster, Germany. Tel: +49 (0)25 01 2 91 06 Fax: +49 (0)25 01 2 91 08	Continuous tunnels
Buhler AG	See Lurgi Umwelt	
CNC (Coop. Nederlandse Champignonkwekers vereniging b.a.)	Postbus 13, 6590 aa gennep driekronenstraat 6, 6596 ma milsbeek, The Netherlands. Tel: +31 (0)485 51 65 41 Fax: +31 (0)485 51 78 23	Large batch tunnel mushroom composter
Compost BASystems b.v.	Amentstraat 15-17, 6039 RA Stramproy, The Netherlands. Tel: +31 (0)495 563 835 Fax: +31 (0)495 561 692	Batch tunnels
Consolidated Envirowaste Industries Inc.	27715 Huntingdon Rd., Abbotsford, British Columbia, Canada, V4X 1B6 Tel: +1 604 856 6836 Fax: +1 604 856 5644 Internet: http://www.envirowaste.com	Agitated bay
Continental Biomass Industries Inc., (CBI)	22 Whittier St., Newton, NH 03858, USA. Tel: +1 603 382 0556 Fax: +1 603 382 0557 Email: info@cbi-inc.com Internet: http://www.cbi-inc.com	Grinder
County Mulch Co.	The Watering Farm, Creeting St. Mary, Ipswich, Suffolk, IP6 8ND, UK. Tel: +44 (0)1449 721 729 Fax: +44 (0) 1449 722 477 Email: countym@anglianet.co.uk	Screen, bagging machine
D&S Recycling Systems Ltd.	Ashley Drive, Bothwell, Glasgow, G71 8BS, UK Tel: +44 (0)1698 307 172 Fax: +44 (0)1698 307 173	Agents for Doppstadt shredders and screens
Dalsem-Veciap b.v.	Postbox 6191, 5960 AD Horst, The Netherlands Tel: +31 77 398 5589 Fax: +31 77 398 6395	Batch tunnels
Diamond Z Manufacturing	1102 Franklin Blvd., Nampa, ID 83687, USA. Tel: +1 208 467 6229 Fax: +1 208 467 6390 Email: diamondz@micron.net Internet: http://www.diamondz.com	Tub grinders

Company	Contact Details	Equipment/Services
Doppstadt Environmental Technology	Steinbrink 13, D-42555 Velbert, Germany. Tel: +49 (0)2052 8890 Fax: +49 (0)2052 88944	Shredders, screens, windrow turners
Double T Equipment Manufacturing Ltd.	PO Box 3637, Airdrie, Alberta, Canada, T4B 2B8 Tel: +1 403 948 5618 Fax: +1 403 948 4780	Batch tunnels
Drager Ltd.	Ullswater Close, Kitty Brewster Industrial estate, Blyth, Northumberland, NE24 4RG, UK Tel: +44 (0)1670 352 891 Fax: +44 (0)1670 356 266	Detection tubes and instruments for ammonia, carbon dioxide, oxygen, hydrogen sulphide, dimethyl sulphide etc.
DS Recycling Systems Ltd.	Carlibar Works, Barrhead, Glasgow, G78 1AB, UK. Tel: +44 (0)141 876 0765 Fax: +44 (0)141 876 9100	Agents for Doppstadt Environmental Technology
Ducker Maschinenfabrik	Wendfeld 9, Postbox 1136, D-4424 Stadtlohn, Germany. Tel: +49 (0)2563 7988 Fax: +49 (0)2563 6934	Shredders
DuraTech Industries International Inc.	PO Box 1940, Jamestown, ND 58402-1940, USA. Tel: +1 701 252 4601 Fax: +1 701 252 0502 Internet: http://www.dura-ind.com	Tub grinders
Ecolo (UK) Ltd.	Laddingford Farm, Laddingford, Maidstone, ME18 6BX, UK. Tel: +44 (0)1622 873 149 Fax: +44 (0)1622 873 150	Odour control system
EcoSci Ltd.	Wolfson Laboratory, Higher Hoopern Lane, Exeter EX4 4SG. UK Tel: +44 (0)1392 424846, Fax: +44 (0)1392 425302, Email:ecosci@eurobell.co.uk Internet:http://info.ex.ac.uk/ecosci/	Suppliers of Ag-Bag Eco-Pod system
Enviroquip Systems Inc. – Re-Tech Division	341 Kings St., Myeertown, PA 17067, USA. Tel: +1 717 866 4710 Fax: +1 717 866 4710 Internet: http://www.re-tech.com	Re-Tech trommel screens
Enviro-Zyme International Inc.	PO Box 169, Stormville, New York 12582, USA. Tel: +1 800 882 9904 Fax: +1 914 878 7917 Email: envirozyme@worldnet.att.net Internet: http://www.envirozyme.com	Microbial-based odour treatment
Erin Matech Ltd.	Birr, County Offaly, Ireland. Tel: +353 509 20161 Fax: +353 509 33007	Fingerscreener and Starscreener screens.
Extec Screens and Crushers Ltd.	Hearthcote Rd., Swadlingcote, Nr. Burton-on-Trent, Derbyshire, DE11 9DU, UK. Tel: +44 (0)1283 212 121 Fax: +44 (0)1283 217 342	Screens

Company	Contact Details	Equipment/Services
Fairfield Service Co.	PO Box 354, Marion, Ohio 43301-0354, USA. Tel: +1 614 387 3335 Fax: +1 614 387 4869	Agitated bay. Circular agitated bin
Fancom b.v.	PO Box 7131, 5980 AC Panningen, The Netherlands. Tel: +31 77 306 96 00 Fax: +31 77 306 9601 Email: fancom@fancom.com Internet: http://www.fancom.com/page_gb/indexgb.htm	Computer control systems for batch tunnels
Farmer Automatic of America Inc.	PO Box 39, Register, GA 30452, USA. Tel: +1 912 681 2763 Fax: +1 912 681 1096	Compost-a-Matic - agitated bay
Farwick GmbH	Beckumer Strasse 51, D-59302 Oelde, Germany. Tel: +49 (0)25 22 93 45 0 Fax: +49 (0)25 22 93 45 45 Email: farwick@t-online.de Internet: http://www.farwick.de	Screens
Fibrestone Technical Affiliates Inc.	2069 Deep Woods Dr., Hendersonville, NC 28739, USA. Tel: +1 704 891 7474 Internet: http://www.fibrestone.com	Diffusion floor plates for compost aeration
Force 3 Software	CRIQ – http://www.criq.qc.ca/english/so/pt/environment/force3/index.html	Compost formulation software
Frontier Manufacturing Co.	PO Box 9176, Brooks, OR 97305, USA. Tel: +1 503 792 3737 Fax: +1 503 792 3795 Email: frontier@gervais.com	Windrow turners
Fuel Harvesters Equipment	2501 Commerce Drive, Midland, Texas 79703, USA. Tel: +1 915 694 9988 Fax: +1 915 694 9985	Tub grinders, screens and windrow turners
Gannon UK Ltd.	Welbourn, Lincs., LN5 0QL, UK. Tel: +44 (0)1400 272 475 Fax: +44 (0)1400 272 303	UK agent for Duratech tub grinders
Gicom b.v.	Plein 11-13, 8256 AZ Biddinghuizen, The Netherlands. Tel: +31 (0)321 332 682 Fax: +31 (0)321 332 784 Email: gicom@compuserve.com Internet: http://www.gicom.nl	Batch tunnels, fixed and modular
Gore, (W.L.) and Associates GmbH	Postfach 1154, D-85636 Putzbrunn, Germany. Tel: +49 (0)89 4612 2731 Fax: +49 (0)89 4612 2726	Gore-Tex – material for covered windrows
GreenMech Ltd.	The Mill Industrial Park, Kings Coughton, Alcester, B49 5QG, UK Tel: +44 (0)1789 400 044 Fax: +44 (0)1789 400 167 Email: sales@greenmech.co.uk Internet: http://www.greenmech.co.uk	Shredders

Company	Contact Details	Equipment/Services
Green Mountain Technologies	Box 560, Brook St. Mill, Whitingham, VT 05361, USA Tel: +1 802 368 7291 Fax: +1 802 368 7313 Email: webmaster@gmt-organic.com Internet: http://www.gmt-organic.com	Comptainer Modular batch tunnel. Compost mixers, screens, and conveyor loaders
GSI Environment	855 Pepin St., Sherbrooke, Quebec, Canada, J1L 2P8. Tel: +1 819 829 0101 Fax: +1 819 829 2717 Email: sherbroo@serrener.ca Internet: http://www.enviroaccess.ca/eng/part-gsi.html	Biotex – fabric for covered windrows
Haybuster Manufacturing Inc.	Box 1940, Jamestown, ND 58402-1940, USA. Tel: +1 701 252 4601 Fax: +1 701 252 0502	Tub grinders
Herhof-Umwelttechnik GmbH	Riemannstrasse 1, D-35606 Solms-Niederbiel, Germany. Tel: +49 64 42 2 07 0 Fax: +49 64 42 2 07 33	Batch tunnels
HOOFMARK (UK) LTD.	First Floor, Unit 24, Philadelphia Complex, Philadelphia, Houghton-le-Spring, DH4 4UG Tel: +44 (0)191 584 5566 Fax: +44 (0)191 584 5577	Small container system
Improcrop Ltd.	3031 Catnip Hill Pike, Nicholasville, KY 40356, USA. Tel: +1 606 887 3241 Fax: +1 606 887 3256	Compost-Aid compost accelerator
JENZ GmbH	Wegholmer Strasse 14, 32469 Petershagen, Germany. Tel: +49 (0)5704 94090 Fax: +49 (0)5704 940947	Shredders, turners
Jones Manufacturing	RR1, PO Box 38, Beemer, NE 68716, USA. Tel: +1 402 528 3861 Fax: +1 402 528 3239	Mighty Giant tub grinder
Keith Manufacturing Co.	PO Box 1, Madras, Oregon 97741, USA. Tel: +1 503 475 3802 Fax: +1 503 475 2169	Keith – walking floor system
Knight Manufacturing Corporation	Brodhead, Wisconsin, 53520, USA. Tel: +1 608 897 2131 Fax: +1 608 897 2561	Compost mixers and spreaders
Kruger A/S	International Division, Klamasageryej 2-4, DK-8230 Abyhoj, Denmark. Tel: +45 87 46 33 00 Fax: +45 87 46 34 20 Email: kab@kruger.dk Internet: http://www.kruger.dk	Compodan – agitated bay system
Lehmann Maschinenbau GmbH	Jocketa, Bahnhofstrasse 34, D-08543 Pohl, Germany. Tel: +49 (0)37439 7440 Fax: +49 (0)37439 74425	MSEK - pretreatment of feedstock

Company	Contact Details	Equipment/Services
Longwood Manufacturing Corporation	816 E. Baltimore Pike (Route 1), Kennett Square, PA, 19348-1890, USA. Tel: +1 610 444 4200 Fax: +1 610 444 9552	LMC RB10X7 Agitated bay
Lurgi Entsorgungstechnik GmbH	Lurgiallee 5, 60295 Frankfurt am Main, Germany. Tel: +49 (0)69 58 080 Fax: +49 (0)69 58 0838 88 Internet: http://www.lurgi.com	Bio-container modular batch tunnels. Buhler agitated bay
Magco Tollemache Ltd.	County Estate, Sutton in Ashfield, Nottinghamshire, NG17 2HW, UK Tel: +44 (0)1623 440 990 Fax: +44 (0)1623 440 117	Shredders, screens, grinders
Maier and Fabris GmbH	Umwelttechnik, Lembergstrasse 21, 72072 Tubingen, Austria. Tel: +43 (0)70 71 72748 Fax: +43 (0)70 71 74114	Waste contamination detector
McLanahan Corporation	PO Box 229, 200 Wall St., Hollidaysburg, PA 16648, USA Tel: +1 814 695 9807 Fax: +1 814 695 6684	Pug mixers
Menart	Chausee de la Liberation 29a, B-7911 Montroeul Au Bois (Frasnes), Belgium. Tel: +32 (0)69 86 82 00 Fax: +32 (0)69 86 82 03	Shredders, mixers, turners, screens
Metallic	F38110 Didier de la Tour, France. Tel: +33 0474 9708 78 Fax: +33 0474 9734 96	Shredders
ML Entsorgungs- und Energieanlagen GmbH	Berliner Strasse 93, D-40880 Ratingen, Germany. Tel: +49 (0)2102 92 02 Fax: +49 (0)2102 92 23 72 [See Lurgi]	Batch tunnel and other composting systems
Morbark	Winn, Michigan 48896, USA. Tel: +1 517 866 2381 Fax: +1 517 866 2280 Internet: http://www.morbark.com	Tub grinder
Morgan Scientific Inc.	151 Essex St., Haverhill, MA 01832, USA. Tel: +1 978 521 4440 Fax: +1 978 521 4445 Email: support@morgansci.com Internet: http://www.morgansci.com	Composting monitoring equipment
Motherwell Bridge Environmental Ltd.	PO Box 4, Logans Rd., Motherwell, ML1 3NP, UK Tel: +44 (0)1698 242 600 Fax: +44 (0)1698 242 609 Email: mgreen@mbgroup.com Internet: http://www.ipa-scotland.org.uk	Dano rotating drum
MTM TRADING LTD	Throshers Corner, Forty Green Rd., Knotty Green, Beaconsfield, Bucks., HP9 1XL, UK. Tel: +44 (0)1494 676 137 Fax: +44 (0)1494 681 979]	Agents for Herhof-Umwelttechnik GmbH
Murtagh Recycling	76 Park St., Luton, LU1 3EU, UK. Tel: +44 (0)1582 480 830 Fax: +44 (0)1582 482 688	Vermere tub grinders

Company	Contact Details	Equipment/Services
Nature Plus	52 Lakeview Avenue, Suite 20, New Canaan, CT 06840, USA Tel: +1 203 972 1100 Fax: +1 203 966 2200	EcoCare enzymatic odour treatment
NaturTech Composting Systems Inc.	PO Box 7444, Saint Cloud, MN 56302, USA. Tel: +1 612 253 6255 Fax: +1 612 253 4976 Email: naturtech@composter.com Internet: http://www.composter.com	Modular batch tunnels
OTV Inc.	450 Lexington Avenue, 37 Fl., New York, NY 10017, USA. Tel: +1 212 450 9038 Fax: +1 212 450 9005	Agitated bay
Peterson Pacific Corp.	29408 Airport Rd., Eugene, OR 97402, USA. Tel: +1 541 689 6520 Fax: +1 541 689 0804 Internet: http://www.petersonpacific.com	Shredder
Pike Lab Supplies Inc.	RR2, Box 710, Strong, Maine 04983, USA. Tel: +1 207 684 5131 Fax: +1 207 684 5133	Recip-eze Compost formulation software
Plus Grow Environmental Ltd.	1A Broadoak Industrial park, Ashburton Road West, Trafford park, Manchester, M17 1RW, UK. Tel: +44 (0)161 872 3022 Fax: +44 (0)161 872 9756	Agitated bay
Polyfelt Geotextiles (UK) Ltd.	Unit C2, Haybrook Industrial Estate, Halesfield 9, Telford, UK. Tel: +44 (0)1952 588 066 Fax: +44 (0)01952 588 466 Internet: http://www.polyfelt.com	Toptex – material for covered windrows
Powerscreen International Distribution Ltd.	Dungannon, N, Ireland, BT71 4DR, UK. Tel: +44 (0)1868 740 701 Fax: +44 (0)1868 747 231	Trommel screens
PSL	Pambry House, 15 Kilmarnock Rd., Winton, Bournemouth, Dorset, BH9 1NP, UK Tel: +44 (0)1202 511 580 Fax: +44 (0)1202 511 680	Agents for TIM shredders, screens and windrow turners
Resource Optimization Technologies	Route #2, Box 495, Cornish, NH 03745, USA. Tel: +1 603 542 5291	ROT agitated bay composting system
Resource Recycling Systems Inc.	416 Longshore Dr., Ann Arbor, MI 48105, USA. Tel: +1 313 996 1361 Fax: +1 313 996 5595 Email: rrsi@recycle.com	Compost Operator Course Guidebook
Rethmann Kreislaufwirtschaft GmbH and Co. KG	Brunnenstrasse 138, 44536 Lunen, Austria. Tel: +43 (0)23 06 106 585 Fax: +43 (0)23 06 106 587 Internet: http://www.rethman.com.au	Brikollare brick composting
Rudnick + Enners GmbH	D-57642, Alpenrod, Germany. Tel: +49 (0)2662 8007 0 Fax: +49 (0)2662 2613	Shredders, mixers, screens

Company	Contact Details	Equipment/Services
Sandberger GmbH	Dittersdorf 11, A-4084 St. Agatha, Austria. Tel: +43 (0)72 77 87510 Fax: +43 (0)72 77 8612	Windrow turner equipment. Covered windrows
SCARAB Manufacturing and Leasing, Inc.	PO Box 1047, White Deer, Texas 79097, USA. Tel: +1 806 883 7621 Fax: +1 806 883 6804	Windrow turners
SCAT Engineering	Box 266, Delhi, Iowa 52223, USA. Tel: +1 319 922 2981 Fax: +1 319 922 2130	SCAT windrow turners
Sevar Entsorgungsanlagen GmbH	Hardeckstrasse 3, D-76185 Karlsruhe, Germany. Tel: +49 (0)7 21 50 010 Fax: +49 (0)7 21 50 01368	Agitated bay
Stinnes Enerco Inc.	Sheridan Science and Technology park, 2800 Speakman Drive, Mississauga, Ontario L5K 2R7, Canada. Tel: +1 905 855 7600 Fax: +1 905 855 8270	Modular batch tunnels
Sutco Maschinenbau GmbH	Britanniahutte 14, D-51469 Bergisch Gladbach, Germany. Tel: +49 (0)22 02 20 05 01 Fax: +49 (0)22 02 20 05 70	Biofix – agitated bay
Taulman Composting Systems	3264 McCall Drive, Doraville, Georgia, USA. Tel: +1 404 455 9415 Fax: +1 404 451 7093	Vertical silo composting system
TEG Environmental plc	8 Hanover Street, Mayfair, London, W1R 9HF, UK Tel: +44 (0)171 290 2623 Fax: +44 (0)171 290 2637	TEG Silo-Cage continuous tunnel
Texel Inc.	245 Ten Stones Circle, Charlotte, VT 05445, USA. Tel: +1 802 425 5556 Fax: +1 802 425 5557	Compostex Windrow cover material
Thoni Industriebetriebe GmbH	A-6410 Telfs, Obermarkt 48, Postfach 85, Austria. Tel: +43 (0)52 62 69 03 0 Fax: +43 (0)52 62 69 03 220	TDM agitated batch tunnel TSM static batch tunnel AirTube – aerated static pile
Traymaster Ltd.	New Rd., Catfield, Great Yarmouth, Norfolk, NR29 5BQ, UK. Tel: +44 (0)1692 582 100 Fax: +44 (0)1692 582 211 Email: sales@traymaster.co.uk Internet: http://www.traymaster.co.uk	Modular batch tunnel, non-agitated bays, turners and shredders
U.S. Filter Corporation	PO Box 36, 441 Main St., Sturbridge, MA 01566, USA. Tel: +1 508 347 7344 Fax: +1 508 347 7049 Email: gormsenp@usfilter.com Internet: http://www.usfilter.com	IPS Agitated bay
Umwelt Elektronik GmbH and Co.	D-73312 Geislingen/Steige, Seitenstrasse 49, Germany. Tel: +49 (0)7331 62319 Fax: +49 (0)7331 68515	Compo-matic oxygen and temperature probes

Company	Contact Details	Equipment/Services
Valoraction Inc.	855 rue Pepin, #100 Sherbrooke, Qc, Canada, J1L 2P8. Tel: +1 819 829 2818 Fax: +1 819 829 2717	Windrow turners
VAM	Marathon 2, 1213 PH Hilversum, Postbus 6500, 1200 HK Hilversum, Netherlands. Tel: +31 (0)35 689 7300 Fax: +31 (0)35 685 6400	Agitated bay
VAR Development Environmental Technologies	Sluinerweg 12 Wilp-Achterhoek, PO Box 184, NL-7390 AD Twello, Netherlands. Tel: +31 (0)55 301 2121 Fax: +31 (0)55 301 1680 email: info@var.nl Internet: http://www.var.nl	Non-agitated bay
VibroPlant plc	Central House, Beckwith Knowle, Otley Rd., Harrogate, HG3 1UD, UK. Tel: +44 (0)1423 533 400 Fax: +44 (0)1423 565 657	Screens
von Ludowig GmbH	D-23738 Johannishof/Lensahn, Germany. Tel: +49 (0)43 63 15 37 Fax: +49 (0)43 63 20 75 email: von.Ludowig.GmbH@t-online.de	Kneer modular batch tunnel
Waste Mechanics Ltd.	The Watering Farm, Creeting St. Mary Ipswich, Suffolk, IP6 8ND Tel: +44 (0)1449 721 602 Fax: +44 (0)1449 721 603| Email: alan@wastemechanics.com	*Sirocco* mobile batch tunnel
Waste to Compost	Old Presbytery, London Rd., Saxton Tadcaster, LS24 9PU, UK Tel: +44 (0)1937 557 392 Fax: +44 (0)1937 557 708	Agents for Ducker mixers and shredders, and Willibald shredders
Waste Treatment Technologies B.V.	Bedrijvenpark Twente 20, 7602 KA Almelo, The Netherlands Tel: +31 (0)546 575 622 Fax: +31 (0)546 574 875	Batch tunnel
Weiss Bio Anlagen GmbH	Industriestrasse 15a, D-35684 Dillenburg, Germany. Tel: +49 2771 8153 0 Fax: +49 2771 41525	Continuous vertical flow system
Western (Richard) Ltd.	D'Urbans, Framlingham, IP13 9RP, UK. Tel: +44 (0)1728 723 224 Fax: +44 (0)1728 724 291	Shredders
Wildcat Inc.	Box 1100, Freeman, SD 57029, USA. Tel: +1 605 925 4512 Fax: +1 605 925 7536	Windrow turners, trommel screens
Wilkie Recycling Systems Ltd.	Mercury House Calleva Park, Aldermaston, Berkshire, RG7 8PN, UK. Tel: +44 (0)118 981 6588 Fax: +44 (0)118 981 9532	Agents for Johli and Mabe shredders
Willibald GmbH	85 Maple Way, Burnham on Crouch, Essex, CM0 8TR Tel: 01621 782 224 Fax: 01621 782 224	Shredders, turners and screens

Company	Contact Details	Equipment/Services
Woods End Research Laboratories Inc.	PO Box 297, Belgrade and Rome Rd., Mt. Vernon, ME 04352, USA. Tel: +1 207 293 2457 Fax: +1 207 293 2488 Email: solvita@woodsend.org Internet: http://www.maine.com/woodsend/	Solvita compost maturity testing system
Wright Environmental Inc.	9050 Yonge St., Suite 300, Richmond Hill, Ontario, Canada, L4C 9S6 Tel: +1 905 881 3950 Fax: +1 905 881 2334 Internet: http://www.compost.wem.ca [	Continuous tunnels
Wright Environmental Management (UK) Ltd	Cedarhurst Rd., Belfast, BT8 4HR, UK Tel: +44 (0)1232 640 972 Fax: +44 (0)1232 640 976]	Agents for Wright Environmental Inc.

16.6 Sources of information on composting on the Internet

Increasing quantities of information on all aspects of composting are available on the Internet, (Border 1995, Riggle, 1996, Barth 1997).

16.6.1 Major composting sites

The following sites are major Internet sources of information on composting and provide links to other composting-related web sites.

Bionet (http://www.bionet.net). A large, Europe-wide web site dealing with all aspects of biological waste management, with specific information on each country.

Composting UK (http://www.dbcc.co.uk). A site run by DBCC that provides links to all of the important composting-related web sites on the Internet.

Composting Association (http://www.compost.org.uk)

The official site of the UK Composting Association

Compost Resource Page: (http://www.oldgrowth.org/compost/). A major source of information on all aspects of composting, including a discussion group on current composting matters.

Cornell Composting: (http://www.cfe.cornell.edu/compost/Composting_homepage.html). Run by Cornell university, this site provides much technical information on all types of composting.

Environmental Protection Agency (US) (EPA): (http://www.epa.gov/osw/). Provides full access to publications and activities of the EPA. Also contains downloadable copies of many important EPA publications.

Composting Council: (http://compostingcouncil.org/index.html). The main composting association in the USA

Composting Council of Canada: (http://www.compost.org/). The web site of the main composting organisation in Canada.

16.6.2 In-vessel composting web sites

The following web sites provide information on many of the commercial in-vessel composting systems described in this report.

Ag-Bag International: (http://www.agbag.com)

Anglian Water Services: (http://www.anglianwater.co.uk)

Bedminster Bioconversion Corporation : (http://www.bedminster.com)

Biomax Inc.

(http://www.enviroaccess.ca/fiches_4/F4-10-96a.html) (CompostAir)

(http://www.enviroaccess.ca/fiches_4/F4-01-96a.html) (Robotcompost)

Fancom: (http://www.fancom.com/page_gb/indexgb.htm)

Gicom Composting Systems: (http://www.gicom.nl

Green Mountain Technology: (http://www.gmt-organic.com)

Kruger: (http://www.kruger.dk)

NaturTech Composting Systems Inc.: http://www.composter.com

Siroccco: (http://www.dbcc.co.uk)

Traymaster: (http://www.traymaster.co.uk)

U.S. Filter Corporation: (http://www.usfilter.com)

Wright Environmental Management Inc.: (http://www.compost.wem.ca)

16.6.3 Bulletin boards (On-line discussion groups)

The following discussion groups allow questions to be asked on any topics relating to composting and organic wastes, and provide much useful current information.

Compost Digest - compost@listproc.wsu.edu

Waste - owner-waste@cedar.univie.ac.at

Leeds University Discussion Group - composting@mailbase.ac.uk

Compost Resource Page - http://www.oldgrowth.org/compost/forum_large/

16.7 Glossary of composting terms

The following glossary highlights some of the terms related to composting that cause confusion, are of a particularly technical nature, or are relatively new to the industry.

Table 16:5: Glossary of composting terms

Aerated static pile composting	A composting process in which shredded and mixed organic material is made into long triangular or trapezoid heaps, typically 3-4 metres wide and 2-3 metres high. The heaps are constructed on top of perforated pipes or a perforated pavement through which air is blown or sucked by fans to provide aeration and control temperature. The heaps are not turned.
Aeration	The process of supplying air to compost to provide oxygen and possibly to control temperature
Aerobic	In the presence or air, or more specifically, oxygen.
Agitated bays	A continuous system of composting in which the composting waste is held within 3-4 metre wide bays with 3-5 metre high concrete walls. Air is normally supplied through the floor of the bays and the compost is turned by a device that travels along the tops of the bay walls.
Amendment	A material (often a waste) added to a feedstock mixture to improve its physical or chemical characteristics
Anaerobic	In the absence of air, or more specifically, oxygen.
Anaerobic digestion	A biological process that takes place in the absence of oxygen during which organic wastes are converted to a compost-like product with the production of carbon dioxide and methane that may be burned to produce electricity.
Batch composting	Composting that takes place on a fixed quantity of feedstock, i.e. not continuous.
Batch tunnels	A type of in-vessel system in which batch composting takes place within a rectangular stainless steel or concrete box with a perforated floor. Air is blown through the floor, often on a recirculation basis, to provide aeration and control temperatures.
Bioaerosol	Air-borne bacteria, actinomycetes and fungal spores, derived from composts, that can cause respiratory problems.
Biodegradability	The potential of a material to be biodegraded
Biodegradable plastic	A degradable plastic in which the degradation results from the action of naturally occurring micro-organisms such as bacteria, fungi and algae
Biodegradation	A degradation brought about by biological activity, especially enzymatic action, leading to a significant change in the chemical structure of the material
Biofilter	A device, often containing mature compost/bark/peat that filters odours from composting process air by means of micro-organisms within the material.
Biosolids	Sewage sludge cake
Civic Amenity Waste	Waste that is taken to Civic Amenity sites by the public. It may be left in a mixed condition or separated to supply relatively clean organic material such as grass cuttings or leaves for composting.
Co-composting	The composting of more than one material at the same time, e.g. source separated household waste and biosolids
Compost	In the context of composting, the end result of a composting process. The term can also be applied to peat-based growing media, although this usage is being discouraged.

Compost	The solid organic product of a composting process that has beneficial use in agriculture or horticulture
Compost activators	Micro-organisms, enzymes or nutrients that when added to feedstock are intended to start the composting process faster.
Compostability	A property of a material to be biodegraded in a composting process.
Compostable	Capable of undergoing decomposition within a composting process.
Compostable plastic	A plastic that undergoes biological degradation during composting to yield carbon dioxide, waste, inorganic compounds and biomass at a rate consistent with other known compostable materials and which leaves no visually distinguishable or toxic products.
Composting	The biological process by which organic wastes are converted by the action of bacteria, actinomycetes, under aerobic conditions, into a more stable product that can be used beneficially in horticulture or agriculture. The composting waste passes through a thermophylic stage during which human, animal and plant pathogens, and weed seeds, are killed.
Composting micro-organisms	Bacteria, actinomycetes and fungi involved in the composting process
Compressed windrow composting	Windrows, rectangular in section, that are used in mushroom composting for the Phase I or thermophilic stage of composting. They are made by windrow formers that compress the material into self-supporting block.
Contained composting	A composting process that take place within some form of reactor, container or vessel.
Contaminated land	Land which has become contaminated, by nature of its previous use or through dumping, with a range of toxic chemical.
Continuous composting	A form of in-vessel composting in which feedstock is added on a continuous or intermittent basis at one end of the vessel while finished compost leaves the other end also on a continuous or intermittent basis.
Curing	See maturation stage
Decomposition	The break down of complex organic materials, such as proteins, fats and carbohydrates, into simpler molecules.
Degradable	Capable of undergoing degradation to a specific extent, within a given time, measured by standard test methods.
Degradable plastics	A plastic designed to undergo a significant change in chemical structure under controlled conditions.
Degradation	An irreversible process leading to a significant change in the structure of a material, typified by the reduction of structural integrity, molecular weight, mechanical strength along with fragmentation.
Disintegration	The falling apart of a material into very small fragments
Enclosed composting	See in-vessel composting. Sometimes used to refer to windrow or aerated static pile composting systems that take place within a building.
Feedstock	The organic wastes used to produce the starting mixture for composting

Forced aeration	The supply of air to a compost with either positive or negative pressure
Garden waste	Organic waste generated in the gardens consisting, for example, of grass cuttings, leaves, tree trimmings.
GPR	Bio-Gas Production Rate for a material, measured in N1 kg^{-1} TS
Green waste	Tree trimmings, grass cuttings, leaves
Growing medium	A product made from a range of possible materials (peat, bark, soil, waste-derived composts), or combinations of these, placed in a container to grow plants.
High rate composting	See high temperature composting stage
High temperature composting stage	The thermophylic or hot stage of composting, achieving temperatures between 30-80°C.
Horizontal flow systems	In-vessel composting systems in which composting waste moves horizontally on a continuous basis
In-building composting	Typically a windrow or aerated static pile composting system that takes place within a closed, or semi-closed, building
Inclined flow systems	In-vessel composting systems in which composting waste moves down an incline on a continuous basis
In-vessel composting	Composting carried out within some form of enclosed environment, such as small containers, or larger stainless steel or concrete structures. Possible containers vary from a few to several hundred tonnes in capacity, may be continuous or batch in operation, and process material in a variety of ways. They are intended to offer a greater control over the composting environment, to optimise this environment, and to contain odours and leachate.
Leachate	Liquid escaping composting waste, often containing high levels of nitrogen and other chemicals, and potentially odour-producing
Maturation stage	The final stage of composting, after the high-temperature or thermophylic stage, during which the chemical , physical and microbial properties of the compost stabilise.
Mesophylic micro-organisms	Micro-organisms that are active at or near ambient or mesophylic temperatures
Mesophylic temperatures	Temperatures at or near ambient
Microbial inocula	Bacteria, actinomycetes and fungi sometimes added to composting feedstock in an attempt to start composting earlier or to otherwise accelerate the composting process
Micro-biological	A process that takes place through the actions of bacteria, actinomycetes or fungi.
Mixers	Devices used to mix the component of a composting feedstock.
Mixing	Part of the pre-composting stage in which the composting feedstock is made as homogeneous as possible.
MBP	Mechanical-Biological Pre-treatment of organic wastes prior to landfill.
MSW	See Municipal Solid Waste
Mulch	A material laid on the surface of soils to reduce moisture loss and to reduce weed growth.

Municipal Solid Waste	Waste collected from households by a local authority and waste collected from Civic Amenity sites and road sweepings. Typically contains a significant proportion of compostable organic matter.
Mushroom composting	The manufacture of compost from cereal straw and animal manures used to grow the commercial white mushroom (Agaricus bisporus). It involves a windrow or Phase I first stage and a second batch tunnel phase.
Non-flow composting systems	Systems in which composting takes place in a batch, as opposed to continuous, basis. The material is not moved during composting.
Open composting	Composting that takes place out of doors and not within a building or container, typically, windrow composting and aerated static pile composting
Organic waste	Waste consisting of animal or plant remains and their manures.
Pathogens	Micro-organisms that can cause diseases of humans, animal or plants
Phase I	A term used in mushroom composting to indicate the first, thermophylic stage of composting in compressed windrows or Phase I tunnels
Phase I tunnels	A term used in mushroom composting to describe a concrete walled composting container (typically 4 metre wide, 3 metres high and up to 50 metres long) with a perforated floor but no roof. Air is blown through the composting waste through the floor but is not recirculated. Is now replacing the first or windrow stage of mushroom composting
Phase II	A term used in mushroom composting to describe the second stage of composting in a batch tunnel using recirculated air.
Phase II tunnels	A term used in mushroom composting to describe a batch composting tunnel that is used to carry out the second (pasteurisation) stage of composting.
Porosity	A measure of the amount of void space in a compost
Post-composting	Processes such as screening, the addition of nutrients, and bagging that occur one composting has finished.
Pre-composting	Processes such as shredding, mixing, and separation that occur before composting begins.
RDF	See Refuse derived fuel
Reactor composting	See in-vessel composting
Refuse Derived Fuel	Organic matter used as fuel
Run-off	See leachate
Screen	A device to separate compost into a range of particle sizes.
Screening	The passing of compost (partly finished or finished) through some form of screen to remove large particles or to separate the material into a range of particle sizes.
Sewage sludge	The product from sewage treatment plants. This can be liquid (dry solids 2-5%) or 'cake' (dry solids 20-25%).
Shredder	A device to reduce the particle size of organic wastes.
Shredding	Passing organic feedstock intended for composting through a shredder to reduce the size of the particles and to increase the active surface area.

Silos	Tower-like in-vessel composting systems in which the feedstock travels downwards on a continuous basis.
Soil improver	Material added to soil to improve its chemical and/or physical properties
SOUR	Specific Oxygen Uptake Rate of a material, measured in $mgO_2\ g^{-1}$ TS.
Source separated household waste	The organic waste component of household waste collected into a separate bin.
Stabilisation	The conversion of active organic material into stable, essentially odour free, compost.
Thermophylic micro-organisms	Micro-organisms that are active at thermophylic temperatures
Thermophylic temperatures	Temperatures significantly above ambient, typically in the range of 30-80°C.
Trommel screen	A type of compost screen, made from mesh of a particular mesh size, in the form of a rotating drum.
Tunnel	See Batch tunnel
Turners	Equipment of various designs used to turn and mix windrows.
Vertical flow systems	In-vessel composting systems in which feedstock enters at the top on a continuous basis, moves down the vessel while composting, and leaves the vessel at the bottom on a continuous basis.
VFG	Vegetable, fruit and garden waste. A term used in the Netherlands and a number of other countries.
Void space	Spaces between the particles of composting waste, typically containing air under good composting conditions.
Windrow composting	A composting process in which shredded and mixed organic material is made into long triangular or trapezoid heaps, typically 3-4 metres wide and 2-3 metres high, that are turned and mixed at intervals using a front-end loader or turner.
Yard waste	Grass cuttings, tree trimmings, flowers and leaves from residential gardens.