COMPOSTING

A LITERATURE STUDY

1989

MAY 1990

Ontario

Environment

Environnement

Jim Bradley, Minister/ministre

ISBN 0-7729-7125-0
PIBS 988

COMPOSTING
A LITERATURE STUDY

1989

Report prepared by:
M.M. Dillon Limited and
Cal Recovery Systems Incorporated

MAY 1990

DISCLAIMER

TABLE OF CONTENTS

1.0 INTRODUCTION 1-1

1.1 Introduction 1-1

1.2 Background 1-1

1.3 Compost Quality 1-1

1.4 References 1-2

2.0 GENERIC COMPOSTING INFORMATION 2-1

2.1 Definitions of Key Terminology and Nomenclature 2-1

2.2 Description of Generic Composting Technologies 2-3

2.2.1 Turned Windrow 2-4

2.2.2 Static Pile (Forced Aeration) 2-5

2.2.3 In-Vessel 2-5

2.2.4 Hybrid Composting 2-7

2.3 Generic Operating and Control Parameters 2-7

2.3.1 Time Requirements 2-7

2.3.2 Temperature Requirements 2-8

2.3.3 Moisture Requirements 2-8

2.3.4 Oxygen Requirements 2-12

2.3.5 Nutritional Requirements 2-12

2.3.6 Particle Size 2-13

2.3.7 Mixing Requirements 2-14

2.3.8 Hydrogen Ion Level (pH) 2-14

2.4 Approaches to Municipal, Commercial/Industrial, and Agricultural Composting 2-14

2.4.1 Municipal Wet/Dry Systems 2-15

2.4.2 Variations on the Wet/Dry System 2-17

2.4.3 Post Collection Separation 2-18

2.4.4 Home Composting 2-21

2.4.5 Co-Composting 2-23

2.5 References 2-24

TABLE OF CONTENTS

3.0 DOCUMENTATION OF EXISTING COMPOST TECHNOLOGIES 3-1
3.1 Introduction 3-1
3.2 Internationally Available Technologies 3-1
3.2.1 Turned Windrow 3-2
3.2.2 Static Pile 3-4
3.2.3 In-Vessel 3-6
3.2.4 Hybrid 3-20
3.3 Canadian Technology 3-22
3.3.1 Channel System 3-22
3.4 Economics of Composting 3-23
3.5 Marketing 3-27
3.5.1 Characteristics and Uses 3-27
3.5.2 Marketability 3-32
3.5.3 Developing Markets 3-39
3.6 References 3-44
3.6.1 Technologies 3-44
3.6.2 Economics of Composting 3-46
3.6.3 Marketing Compost Products 3-47

4.0 EVALUATION OF REPRESENTATIVE NORTH AMERICAN FACILITIES 4-1
4.1 Operating and Proposed Composting Facilities in Canada 4-1
4.1.1 Municipal Programs 4-1
4.1.2 Private Sector Composting Initiatives in Ontario 4-3
4.2 United States 4-3
4.2.1 Introduction 4-3
4.2.2 Sewage Sludge 4-4
4.2.3 Municipal Solid Waste 4-8
4.2.5 Yard and Garden Debris 4-12

TABLE OF CONTENTS

4.2.6 General Summary and Conclusions 4-16
4.3 References 4-17

5.0 EVALUATION OF REPRESENTATIVE INTERNATIONAL FACILITIES 5.1
5.1 Introduction 5-1
5.2 Federal Republic of Germany 5-1
5.3 France 5-3
5.4 Italy 5-5
5.5 Japan 5-5
5.6 South America 5-8
5.7 Soviet Union 5-8
5.8 Switzerland 5-9
5.9 United Kingdom 5-10
5.1 References 5-10

6.0 DOCUMENTATION OF POLICIES, REGULATIONS, STANDARDS AND/OR GUIDELINES 6-1
6.1 Compost Quality and Standards/End Use Regulation 6-1
6.1.1 North America 6-4
6.1.2 International 6-8
6.2 Compost Facility Siting and Approvals 6-15
6.3 Health and Safety Requirement 6-17
6.4 Hazardous Waste Handling, Storage, and Disposal 6-19
6.5 References 6-20

7.0 OTHER EMERGING TECHNOLOGIES 7-1
7.1 Irradiation of Sewage Sludge for Composting 7-1
7.1.1 Introduction 7-1
7.1.2 Sludge Irradiation Experience and Regulation 7-1
7.1.3 Effects of Irradiation on Pathogens 7-2

TABLE OF CONTENTS

7.1.4 Summary 7-3
7.2 References 7-4

8.0 ALTERNATIVES TO COMPOSTING 8.1
8.1 Introduction 8-1
8.1.1 Animal Feed 8-1
8.1.2 Biogas Production 8-1
8.1.3 Landfarming 8-2
8.2 References 8-4

9.0 CONCLUSION 9.1

APPENDIX A LITERATURE SEARCH
APPENDIX B PARTIAL LIST OF VENDORS AND FACILITIES

EXECUTIVE SUMMARY

Composting is a process used since antiquity to convert organic waste materials, both vegetable and animal, to a rich, humus-like soil amendment used in agriculture. Composting is an aerobic decomposition process in which organic matter is naturally oxidized to simple chemical compounds with the accompanying release of heat, water vapour, and carbon dioxide. The heat release also causes the destruction of harmful pathogens and weed seeds in the compost. Successful composting depends primarily on adequate temperature and moisture control, oxygen supply and nutrients to feed the microbial populations.

Potential raw materials for composting include the compostable fraction of municipal solid waste, yard, garden and grass leaf wastes, agricultural crop residues and animal manures, food processing wastes, forest products and paper production wastes and other biodegradable wastes from industry and other sectors of society. The primary objective of composting is to recover and recycle a valuable resource in an economic and environmentally acceptable manner.

The literature has been surveyed to provide this state-of-the-art report on composting science, operational practices and compost production systems around the world. The report provides definitions of key terminology and nomenclature and a description of generic composting technologies. The process technologies are grouped in four categories: turned windrow, static pile, in-vessel and finally, hybrid systems which contain combinations of the first three. This section is followed by a description of generic operating and control parameters in compost production.

A discussion of solid waste collection systems and waste storage is followed by a discussion of the advantages of household source separation and collection procedures such as the wet/dry system and the separate collection of yard and garden wastes, food wastes and co-composting. The advantages of both pre-collection separation and post-collection separation are examined. Means of post-collection separation of components in the solid waste stream are discussed including screening, air classification, and size reduction.

The section on home composting describes the biological principles involved such as the lower volumetric limit for effective pathogenic kill, odour control, aeration and environmental constraints to avoid nuisance complaints.

The economics of composting are discussed and comparative cost information on selected North American compost facilities is provided. Marketing of the compost is a factor limiting widespread utilization of this waste reduction process. Data on North American and international composts, their chemistry, typical uses and typical markets are listed. Many approaches to compost market development have been tried with varying degrees of success. The key elements of a marketing program and the need for public education on the uses of compost is reviewed.

A discussion of existing compost technologies follows and many of the established manufacturers and suppliers and their proprietary composting production systems are reviewed. Representative North American facilities are evaluated. Representative international facilities are also evaluated in some detail. Useful lessons can be learned from the study of many of these facilities and the implementation of national policies on composting. Legislation, regulations, standards and guidelines in various North American and European jurisdictions are reviewed.

The future potential for implementing municipal solid waste programs in North America appears to be bright. Obstacles that must be removed before the future potential is attained are discussed. The composting of yard and garden wastes is a high-profile public and municipal concern. Collection strategies to take advantage of the availability of this organic resource and their respective operating systems are reviewed.

Each section of the study is followed by a comprehensive bibliography that should be useful to the composting practitioner in Ontario.

1.0 INTRODUCTION

1.1 Introduction

The Ontario Ministry of the Environment (MOE) is in the process of developing guidelines and standards for large scale compost production, quality control, end use applications and facility siting. These guidelines will help to ensure that compost can be produced and used without adversely affecting human and animal health, food production and the natural environment.

In order for the MOE to develop these guidelines, an up-to-date overview on state-of-the-art composting is required. Existing government and industry regulations and standards that relate either directly or indirectly to composting, in Ontario and other jurisdictions, have been outlined in this study. A worldwide literature review of existing and emerging composting technologies has been documented as well.

1.2 Background

Interest in composting has increased dramatically in recent years. Rising public concern about incineration and landfilling has led to a renewed interest in other waste disposal methods; one of which is composting.

In recent times, attention has been given to using nature's self-cleaning and self-renewal processes to deal with the growing volumes of refuse generated by modem society. Most modem cities now have sewage treatment plants which employ nature's processes to convert organic materials into a sludge that is separated from water, which then is clean enough to return to our rivers and streams.

Until recently, landfills seemed to be the appropriate and least expensive way for communities to deposit their solid waste. Now, however, that method is less acceptable and nature's composting process is being used more and more to deal with the quantities of refuse generated daily in modem communities. A significant portion of the municipal solid waste (MSW) stream is compostable and therefore composting has the potential to divert a large proportion of material from the more traditional disposal methods, landfill and incineration (EFW). It is important that the compost produced be of the highest quality so that if used in agriculture, it will not adversely affect human and animal health, food production and the natural environment. Composting facilities must be designed and operated to minimize nuisance and impacts on public health and the natural environment.

To handle these large volumes of municipal waste, the process of decomposition has to be speeded up. The microorganisms in the waste are given an environment which allows them to grow rapidly and work at peak efficiency in breaking down the waste. To do this, the microorganisms need air, water and nutrients.

1.3 Compost Quality

In an attempt to standardize compost specifications, and encourage improvements in MSW compost quality, an international committee of recognized experts has recently defined composting (the process) and compost (the product) as follows [1]:

- Composting - A controlled biooxidative process that:
  - involves a heterogeneous organic substrate in the solid state;
  - evolves by passing through a thermophilic stage and a temporary release of phytotoxin; and
  - tends to the production of carbon dioxide, water, minerals and stabilized organic matter (compost).
- Compost - The stabilized and sanitized product of composting which is beneficial to plant growth. It has undergone an initial rapid stage of decomposition and is in the process of humification (stabilization stage).

These definitions are useful in that they serve as a baseline in determining compost quality specifications.

First order requirements include stabilization of the organic material, that is, biological degradation and mineralization of the more rapidly oxidized, low molecular weight organic constituents. This accomplished, the odour production potential of the compost is minimized. In addition, sanitation, the destruction of human pathogens, is simultaneously achieved, primarily due to the heat production achieved during the early, most rapid, stages of the composting process. Weed seeds are also killed in the process. (See Figure 2-2.)

Composting should be characterized as a two part process. The first stage primarily involves microbial degradation or breakdown of the lower molecular weight organics, leading to initial stabilization and sanitation of the product. In the second phase, degradation or biooxidation of organic material continues to take place, albeit at a lower rate and primarily involving higher molecular weight organics. However, there is a shift during this period to synthetic activity as well, primarily resulting in the formation of increasing quantities of humus in the compost.

Inclusion of contaminants, heavy metals and hazardous organic materials greatly reduces compost quality, applicability and marketability. The input of these materials is reduced by not composting solid wastes from industrial sources, using well trained picking line operators, not shredding wastes prior to composting, and careful screening and final air separation. Public education and the institution of voluntary source separation programs such as wet/dry systems also have a significant effect in reducing hazardous contaminants in compost.

The quality of the compost will directly affect its end use. High quality composts may find end uses m horticulture and landscaping. Poor quality composts may only be suitable as landfill cover and reforestation.

1.4 References

[1] F. Zucconi and M. de Bertoldi. BioCycle, 56 pp. (May-June 1987).

2.0 GENERIC COMPOSTING INFORMATION

Composting has long been recognized as a means of solid waste management. Since early history, composting has been used to process various organic wastes into a humus-like material suitable for use as a soil amendment. Scientific studies of operating parameters for the compost process were begun in the early 1940s. Nevertheless, for purposes of clarity and completeness, some "generic" information on composting (including definitions of key terminology and descriptions of processing, operating and control parameters, and approaches) is provided in this section.

2.1 Definitions of Key Terminology and Nomenclature

This section begins by defining three terms that are basic to all discussions concerned with municipal solid waste (MSW). The three terms are "garbage," and "rubbish," and "refuse." In the terminology used in the professional literature during the past forty years, the designation "garbage" has been restricted to food preparation (kitchen) wastes and to highly putrescible wastes in general. All other components of residential municipal solid waste (including beverage containers, paper, scrap metal, and a variety of other components) bore the collective label of "rubbish." These two elements (garbage and rubbish) collectively were referred to as "refuse."

This simplistic division of municipal solid waste into garbage and rubbish does pose the difficulty of how to classify yard wastes. In the early classification, green (herbaceous) material usually was classified as garbage and dry or woody material, as rubbish. Currently, these materials are collectively referred to as "yard and garden debris."

With the increasing popularity of solid waste as a subject matter in the popular literature, has come a softening of the distinctions between the terms garbage, rubbish, and refuse. A trend has developed to use the terms garbage and refuse synonymously. Also with this trend has come the use of the term "wet fraction" to refer to garbage as defined above.

"Composting" has been given many definitions in the literature. The following engineering version is appropriate for composting as a waste treatment option and has been fairly widely accepted [1-3]:

> "Composting is the biological decomposition of wastes of plant or animal origin under controlled circumstances to a condition sufficiently stable for nuisance-free storage and for safe use in land application."

The definition sufficiently distinguishes composting as it occurs in nature from the restrictive sense of a waste treatment option. Key terms in the definition are: 1) biological decomposition; 2) under controlled conditions; and 3) sufficiently stable. Inclusion of the term biological decomposition implies that composting as a waste treatment option is for the most part restricted to organic wastes. Under special conditions, however, some microorganisms can attack materials not of living origin. The specification, under controlled conditions, distinguishes engineered composting from the simple decomposition that takes place in an open dump or in a feedlot. The third term, sufficiently stable, is an important requirement to any compost operation. For a compost product to be innocuous with respect to environmental impact and effect on plant growth, it must be sufficiently stable. The requirement also provides a basis for comparing one compost system with another.

Other key terminology of importance in the discussion and understanding of composting are provided below.

Aeration	The process of exposing composting material to oxygen.
Aerobic	A process or condition occurring in the presence of oxygen.
Anaerobic	A process or condition occurring in the absence of oxygen.
Biological Decomposition	The process of breaking down organic materials through the use of microorganisms into component parts or basic elements.
Bulking Agent	Material used to add volume to composting feedstocks, aids in aeration.
C/N	The ratio of carbon to nitrogen.
Co-composting	Composting of two or more waste streams simultaneously.
Compost	Relatively stable humus-like material resulting from the composting process.
Curing	The stage during which materials that are more resistant to breakdown are stabilized; also known as maturation.
Heavy Metals	Elements including cadmium, mercury, lead and chromium which may be found in the waste stream.
Humus	Organic materials resulting from decay of plant or animal matter.
In-vessel	A method of composting in which the compost is mechanically mixed and aerated in a container.
Leachate	Liquid formed by water percolating through a mass of solid waste or compost and extracting dissolved or suspended materials from the mass.
Limiting Factor	The parameter in lowest supply that limits growth and activity of the organisms under consideration.
Mesophyllic	Term popularly applied to mesophiles, i.e., organisms that grow at moderate temperatures. The mesophyllic temperature range usually is considered as being between 8° and 50°C.
Microorganisms	Microscopically small living organisms that metabolize waste materials.
Residuals	Materials removed from the feedstock to the composting process or from the finished compost. Residuals may require landfill disposal.
Sludge	A semi-liquid residue remaining from the treatment of municipal and industrial water and wastewater.
Stability	The state at which the composted material can be stored without causing a nuisance or can be applied to the soil without causing problems.
Static Pile	A windrow composting method in which aeration is accomplished either by forcing or drawing air through the composting mass by way of ducts generally installed at the base of the pile.
Thermophilic	Term applied to thermophiles, i.e., organisms that grow at high temperatures. Thermophilic temperatures are usually higher than 50°C.

Windrow	An elongated pile of material.
Yard and Garden Debris	Leaves, grass clippings. prunings, etc. discarded from yards and gardens.

2.2 Description of Generic Composting Technologies

The technology of composting involves three major steps: 1) preparation of the raw material or substrate; 2) the compost process itself; and 3) grading of the final product. This section deals with the second step, the compost process itself. Process technologies can be grouped under four categories:

- turned windrow;
- static pile (forced aeration);
- in-vessel; and
- hybrid (a combination of the above elements).

In reality, the fourth category is an artifice to accommodate the many miscellaneous combinations of the first three.

Each system basically expresses a particular approach to accomplishing aeration of the composting mass. (Exceptions are the very few systems that call for an anaerobic phase before or after the aerobic phase.) Of course, supplying aeration is not the sole objective of system design. Other objectives are providing environmental and operational conditions that approach the optimum for the active microbial populations.

Because a prime objective of each technology is that of accomplishing aeration, the descriptions of the technologies are preceded here with a discussion of methods of aeration: agitation, injection, and a combination of the two.

Agitation can be done by turning, tumbling, and stirring. The term "turning" refers to the successive tearing down and reconstruction of a windrow. Turning exposes the composting material to air and renews the supply of O_2 in the interstices in the windrow. Tumbling involves cascading the composting material to as to expose the particle surfaces to ambient air. It may be accomplished by passing the composting material through a rotating cylinder equipped with internal vanes. Tumbling also may be done by dropping the composting material from a conveyor belt installed on a frame that moves on rails placed at the bottom of a rectangular tank (bin). The belt scoops up and then drops the composting material. Stirring is done by passing a plow-like device or an auger through the composting material.

Air injection (forced aeration) is perhaps the least expensive of the aeration methods. As the name indicates, it is accomplished by forcing or drawing air through the composting mass. Injection often is used in combination with agitation. Individual in-vessel compost systems may depend entirely on agitation or injection, or may use them in combination.

As mentioned earlier, the compost technologies have been grouped under four categories: turned windrow static pile, in-vessel, and hybrid. The first two categories (turned windrow and static pile) are both classified as "open" systems inasmuch as they are not contained within a structure. The classification, however, does not exclude enclosing the operation in a shelter or building. Open systems more commonly are termed windrow systems. The term "windrow" simply means "an elongated pile" and can apply equally to windrows that are aerated by way of turning and to those that are subjected to forced aeration.

The third compost technology listed above (in-vessel) can be categorized as an "enclosed" system because the compost is mechanically mixed and aerated in a structure. To conserve on capitalization, maintenance, and operational costs, many in-vessel systems call for the initial stage of the compost process to take place in a reactor and all succeeding stages in windrows. Such combinations may be loosely termed "hybrid" systems. In practice, almost all in-vessel designs can be classified as hybrids. Typical retention periods of composting material in the reactor are not sufficiently long to permit adequate stabilization and, consequently, further treatment outside the confines of the reactor generally is needed.

2.2.1 Turned Windrow

As stated earlier, turning is the term applied to the tearing down and reconstruction of the windrows of material being composted. Although turning can be done manually (i.e., with a pitchfork), mechanically (i.e., with a front-end loader) or both, manual turning is impractical under modem conditions and with volumes larger than one or two cubic meters. Front-end loaders, bulldozers or comparable machines are suitable only for small-scale operations because of capacity and quality of turning limitations. There are several types of large-scale turning equipment on the market. They differ among themselves with respect to effectiveness and durability. According to their promotional literature, many of the large mechanical turners can process as much as 900 tonnes/hour of waste. Although essential for most sewage sludge and MSW compost operations, large-scale turning equipment probably would be beyond the financial resources of most yard waste compost projects.

The ideal turning pattern is one in which the outside layer of the original windrow becomes the interior of the rebuilt windrow. At a minimum, care should be taken that at least at some time during the compost cycle, every particle of material is in the interior of the pile. Less than ideal turning patterns can be compensated for by increasing the frequency of turning.

In practice, frequency of turning is a compromise between oxygen demand and economic and technological feasibilities. Nature of the waste and its structural strength and moisture content are important determinants. Other factors are pathogen kill, uniformity of decomposition, and the desired rate of composting. For example, increasing the frequency of turning can decrease the residence time to 1 to 2 months as compared to the 6 to 12 months that would be required at a turning frequency of only once a month. Less frequent turning is preferable for operations involving a waste with a low moisture content or one consisting of structurally firm particles.

The turned windrow approach calls for stacking the material to be composted into a pile that has the shape of a windrow with a more-or-less triangular cross-section. The cross-sectional shape can be changed to fit special conditions. If the pile is turned by machine, the configuration is the one imparted by the machine.

Although ideally, the windrow should be from 1.5 to 1.8 m (5 to 6 feet) in height, the practical height will be a function of the type of turning machine. Optimum height is a function of the tendency of the material to compact under its own weight.

Width of windrow is determined by convenience, expediency, and type of turning equipment. Width is not critical because the oxygenation by diffusion supplies very little of the oxygen needed in the composting mass. Usually, the width is from 2.4 to 4.5 m (8 to 15 feet).

Windrow length should befit the operation and site configuration. To set up a semi-continuous system, each day's input of raw waste is added to one end of the windrow or, for large-scale operations, by placing each day's input into a new windrow. Basically, continuity comes from adding fresh material to one end of the windrow and removing composted material from the other end.

Aside from the usual array of factors, area requirement depends upon the capacity and working space requirements of the type of turning equipment utilized.

2.2.2 Static Pile (Forced Aeration

Essentially, the static pile approach calls either for forcing (injecting) air into the composting mass, or conversely, for drawing air through the composting mass. The composting material may or may not also be turned. The system involves the following steps; 1) mixing of the raw waste with a bulking agent (if required); 2) construction of the windrow; 3) onset and completion of the compost process; 4) screening of the bulking agent from the composted mixture (if required); 5) curing; and 6) storage.

Construction of a static pile windrow is begun by laying a grid of perforated pipe on the compost pad. The grid is connected to a fan. The grid is covered with a layer of bulking agent or finished compost. The material to be composted is then stacked on the covered grid. The substrate is topped with a 30 cm (1 foot) layer of finished compost. If desired, the windrows may be sheltered from the elements.

Because the optimum rate of aeration depends upon several site and material-specific factors, it should be determined experimentally for each operation. Typical air flow rates for static pile windrows are between 120 and 170 m^3/h.

The static method is not applicable under all conditions or to all types of materials. Chances are that the static pile method may not be effective with wastes characterized by one or more of the following: 1) a large particle size; 2) a large and varied particle size distribution; 3) a tendency to clump; or 4) a high moisture content. It is best suited to materials that are relatively uniform in particle size and whose particle size does not exceed 3.8 to 5 cm (1.5 to 2 in.) in any direction. Granular materials are best. Inappropriate size distributions for the bullring agent or inaccurate ratios of bulking agent to waste tend to constrict the air flow. The outcome is that areas of relatively slow degradation and foul odours (anaerobic pockets) are formed.

Probably the static pile approach would be successful with mixtures of dewatered food waste or lawn clippings bulked with the chopped woody fraction of yard debris, straw, or dry leaves. Forced aeration is very useful for composting yard waste. Since the static pile approach is most effective with wastes that are granular and relatively homogeneous, it has had its most widespread application in sewage sludge composting.

2.2.3 In-Vessel

The objective in the design of in-vessel systems should be to provide the best environmental conditions, particularly, aeration, temperature, and moisture. Unfortunately, the design of most in-vessel systems falls short of that objective. Almost all in-vessel systems use forced aeration in combination with stirring, tumbling, or both.

In-vessel systems can be classified into the two broad groups: 1) rotating drum; and 2) tank (horizontal and vertical).

2.2.3.1 Rotating Drum

The rotating horizontal drum is one of the earliest in-vessel systems to rely upon tumbling as the primary mode of aeration. The tumbling material in the drum is exposed to air which is continuously renewed with air forced into the drum interior through a series of nozzles installed in the drum wall. In most versions, the drum is a long, slightly inclined cylinder about 2.7 m (9 feet) in diameter. The drum is rotated at a few (less than 10) revolutions per minute (rpm). According to the promotional literature, the retention periods in the drum may range from 1 to 6 days. Because the degree of stability attainable in such a brief time is insufficient, the material must be further composted over an additional period, which usually is on the order of 1 to 3 months. This period serves as the maturation (curing) stage. The common procedure is to set up a two-stage process flow in which the first stage is a rotating drum and the second is a windrow (either turned or static pile).

High capital, operational, and maintenance costs restrict the horizontal drum approach to large-scale applications, such as composting municipal refuse and co-composting.

2.2.3.2 Horizontal Tank

Rectangular

An in-vessel system that has much in its favour, involves the use of a long rectangular, horizontal tank and incorporates a combination of tumbling and forced aeration. Tumbling is accomplished by periodically passing a travelling endless belt through the composting material. In addition to the tumbling, air is forced through the perforated bottom of the tank and into the composting mass in the tank.

In the operation, suitably prepared waste is placed in the tank. At the end of a 6- to 12-day retention period, the material is removed from the tank and is windrowed over a period of one to two months. Although somewhat expensive for composting yard wastes, this system probably would be well suited for MSW, sewage sludge, mixtures of MSW and sludge, and properly bulked high-moisture food wastes. Times involved (in tank plus required windrowing) range from one to two months.

Cylindrical

Another version of the horizontal tank is a circular tank that relies upon a combination of forced aeration and stirring. The tank is equipped with a set of hollow augers perforated at their edges and supported by a bridge attached to a central pivoting structure. The bridge with its set of augers is slowly rotated, as also are the augers. Air forced through the perforations is distributed into the composting material. Retention time varies. If it is less than three weeks or so, the discharged material must be windrowed until stability is reached.

2.2.3.3 Vertical Tank

As the term indicates, this version of in-vessel systems consists of vertically-oriented tanks (i.e., silos) which rely upon forced aeration and stirring. A problem that besets such systems is the difficulty in sufficiently aerating the upper layers of the composting material without unduly cooling the lower layers.

One such system involves the use of three completely enclosed vessels. A special feature of this version is a rotating screw device installed at the bottom of the vessel for discharging the compost. One of the three tanks serves as a storage container for carbonaceous material intended for use as a bulking agent and for correcting the C/N. The composting process takes place in the second and third vessels -- the "bioreactor" and the "cure reactor." Air is fed continuously into the bottom of the bioreactor, with positive control maintained by pulling air off the top. Composted material from the bioreactor is transferred into a cure reactor, in which further stabilization takes place. Air is fed continuously into the cure reactor to maintain aerobic conditions and to remove moisture due to evaporative cooling. Since the retention period in the bioreactor is on the order of two weeks, the normal daily operating sequence begins with the bioreactor outfeed discharging approximately 1/14 of the contents into a conveyor. The conveyor transports the material to the top of the cure reactor. At the same time, the outfeed device in the cure reactor is started and final compost product is discharged. Retention time in the cure reactor is about 20 days. Problems frequently encountered in the operation of the units are: 1) a tendency of the material "to bridge" over the discharge screw; 2) failure of the rotating screw; and 3) excessive condensation on the upper layer of the bioreactor. The system originally was designed for sewage sludge and manure composting. Up until now, most of the experience has been with sewage sludge. The extent of the experience with municipal refuse has been limited to one or two installations in western Europe.

2.2.4 Hybrid Composting

The broad category, "Hybrid Composting," was discussed in the introductory paragraphs of Section 2.2, and in the subsection on in-vessel composting. Hence, no further discussion on the subject is had at this time other than to point out that almost all in-vessel systems are potential candidates for hybridization.

2.3 Generic Operating and Control Parameters

This section is introduced by a brief explanation of the biology of the compost process so as to facilitate the description of the operating and control parameters.

In practice, composting takes place in two stages. The transition from the first to the second is gradual and uninterrupted. The first stage is the active stage in which biological activity is proceeding at its highest rate. Heat generation is such that in the absence of heat dissipation, the temperature of the mass soon reaches 60 to 70°C. In this stage, readily biodegradable material is decomposed to less readily degradable intermediates. With the disappearance of the readily available nutrients, the temperature of the mass drops because of a slowing of microbial activity. This second stage is known as the curing (maturation) stage. It ends when the residue reaches the required degree of stability. Hence, an important consideration in the evaluation of a compost systems is the fact that the compost process is finished only upon the completion of the curing stage.

Composting is essentially a microbial process in its early stages. However, as the process continues, microscopic protozoa, macroflora and macrofauna (specifically the macroinvenebrae) may appear. Among the latter, earthworms (e.g. *Lumbricus terestris, L. rubellus, Eisenia foetida*) periodically have attracted attention due to claims made by some individuals, who attributed certain useful properties to the worms.

Usually, the microflora active in composting are present in the material to be composted. Consequently, no inoculums are required. In the unlikely event that it might be beneficial. mass inoculation can be done by recirculating some end product or by introducing a massive dose (about 10% of the mass) of microorganisms specifically cultured for the purpose. The general experience has been that no other additives (enzymes, hormones) are needed [4,5].

Because microbes are the essential agents in composting, factors that affect their growth and activity simultaneously determine rate and extent of composting. These factors constitute the operating and control parameters. Among the more important factors are time, temperature, moisture, nutrition content, oxygen, and mixing.

2.3.1 Time Requirements

With respect to the overall compost process, the parameter of time should be an interval sufficiently long to permit the process to reach its desired goal. Therefore, the compost process is sufficiently complete as soon as the composting mass has been stabilized such that: 1) it can be stored without causing nuisances; and 2) it has reached a stage of maturity at which it is not inhibitory to plant growth. At present, several sets of standards and methods are being developed and proposed for measuring stability of the finished compost. Among the measures receiving attention are the carbon-to-nitrogen (C/N) ratio, and seed germination and growth tests.

With reference to a stage of the process, the interval should be long enough to permit activities peculiar to that stage to reach a satisfactory conclusion. For example, by the end of the initial stage, the necessary microbial populations should have: 1) begun the logarithmic rate of growth phase; and 2) become sufficiently active to cause the temperature of the pile to begin a sharp ascent to thermophilic levels. By the end of the active stage, microbial activity should have begun to slow and temperature to plateau immediately prior to a gradual drop. By that time, the readily decomposed components should have been converted to intermediates suitable for eventual breakdown in the curing stage. The curing interval is particularly important because it must be long enough for the composting material to *have* reached the final level of stability.

When used in reference to a continuous culture, the interval is the time the average particle is in the reactor or in the body of the composting windrow. The term applied to the interval may be any one of the following three: retention time, detention time, or residence time. The terms are used interchangeably. It should be noted that the terms are applicable to any continuous system, whether it be an in-vessel system, a turned windrow, or a static pile.

One sampling of time ranges is given in Table 2-1. The times are total times, i.e., they include lag, active, and full curing stage.

2.3.2 Temperature Requirements

With the exception of some in-vessel systems, little is done about temperature unless a significant aberration is observed. The underlying reason for the laissez-faire approach is the self-heating characteristic typical of an actively composting mass. Because of this characteristic, unless something intervenes, the initially mesophyllic (ambient) temperatures of a composting mass rapidly are replaced by thermophilic temperatures. This rapid rise is a mark of the active stage of composting. Eventually, as microbial activity diminishes, the temperature returns to mesophyllic levels during the curing stage. A typical temperature curve is presented in Figure 2-1.

Temperature approaches a limiting factor in the composting process when it exceeds 60°C. Temperatures greater than 60°C tend to inhibit bacterial activity. Methods of lowering an unfavourably high temperature depend upon the type of system being used. However, the usual method is to increase the rate and extent of aeration.

Too slow a rise of temperature, or complete absence of a temperature rise, in an adequately insulated composting mass is an indication of inhibited microbial proliferation and activity due to some operational or environmental imbalance or inadequacy (e.g., aeration, nutrition, moisture). The attainment and maintenance of thermophilic temperatures for a time period is a requirement, mostly with respect to weed and pathogen control. Recommended temperatures for inactivation of plant pathogens and weed seeds are presented graphically in Figure 2-2.

2.3.3 Moisture Requirements

The role of moisture in the composting process begins with the microbes involved in the process and extends to and includes the moisture required for rendering nutrient chemicals available to the microbes and for transporting other substances. With respect to the microbes, it is an essential part of their assimilatory, metabolic, and reproductive mechanisms. Its importance is emphasized by the fact that all activity ceases when the moisture content drops to about 8% or lower. Accordingly, the closer that minimum is approached, the slower will be bacterial activity. In practice, it is advisable to keep the moisture level at a minimum of about 48%, but the actual permissible range is between 45% and 55% [2].

With respect to maximum permissible moisture content, if it were not for certain physical, technological, and practical constraints, the ideal moisture content would closely approach 100%. Indeed, the wastes treated by way of the conventional aerobic oxidation systems used in wastewater treatment are in this category. However, as far as composting in the accepted sense of the term is concerned, certain factors necessitate a significant lowering of the maximum permissible moisture content. The most important of these factors is the oxygen requirement and means of meeting the requirement.

Maximum permissible moisture content and oxygen are closely interrelated in compost practice. Regardless of method of composting, the O_2 supply to the individual microbes must come from the air contained in the interstices between particles of wastes and from the ambient air. As the moisture

TABLE 2-1. Examples of Composting Times* [2].

Type of Waste		Time(weeks)
Yard and park debris(including grass clippings)		4 to 8
Leaves (separately collected)	- C/N adjusted	4 to 8
	- C/N not adjusted	24 to 52
MSW - with or without sewage sludge (pre-processed -including size reduction)		8 to 24
Sewage sludge(suitably bulked)		6 to 10
Animal manure and associated wastes		6 to 18
Assorted food processing wastes (appropriately pre-processed or bulked)		6 to 18

* These composting times are to the same stability criterion.

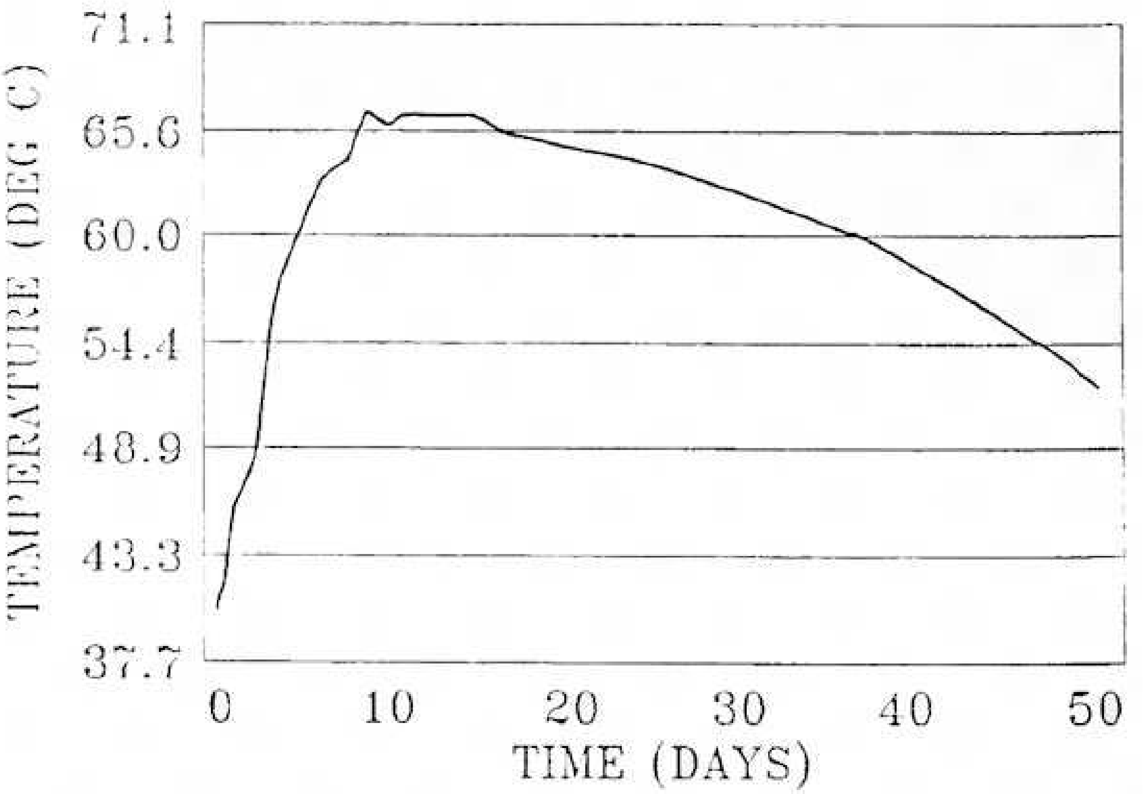
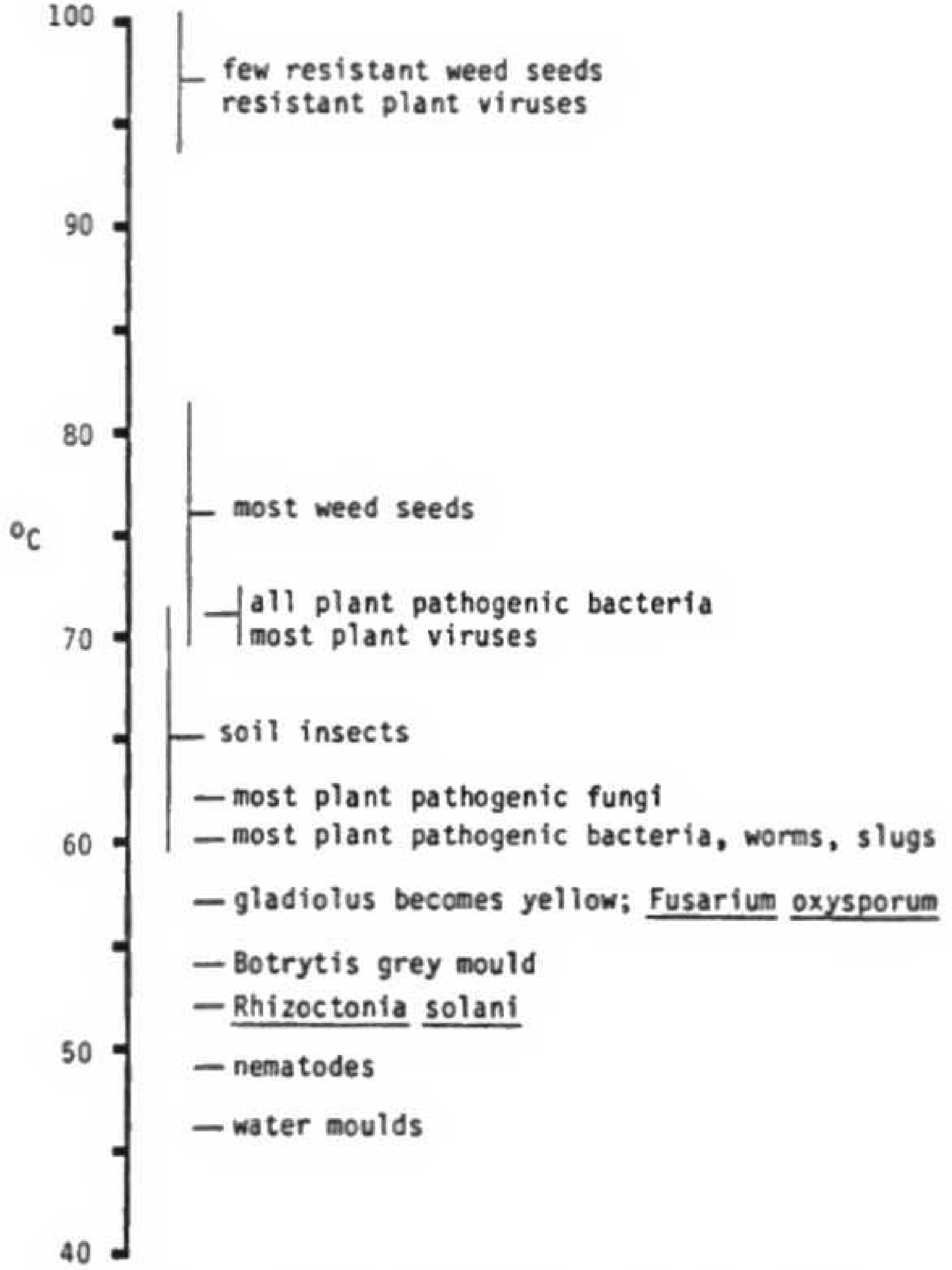


FIGURE 2-1. Typical Temperature Curve [2].



Using external heat for 30 minutes under moist conditions.

FIGURE 2-2. Plant Pathogens: Sterilization Temperatures* [21].

content increases, more air is displaced from the interstices and, hence, less O_2 is available. As a result, the maximum permissible moisture content is that level at which sufficient air remains in the interstices to assure an adequate supply of oxygen, but above which oxygen becomes limiting. The level depends upon the extent to which individual particles maintain their original shapes after being wettened or compressed.

The inadequate structural strength of material such as cannery wastes, sewage sludge, and fresh manure, can be compensated by the addition of a bulking material. A bulking material is one that maintains its original shape upon being mixed with an amorphous waste. Examples of bulking materials are wood shavings and chips, straw, dry leaves, and corn stalks. Mixtures that have mostly paper (e.g., sewage sludge bulked with refuse) have an upper permissible moisture content of only 55% to 65%. (Incidentally, the maximum permissible moisture content for municipal refuse is on the order of 55%.) On the other hand, the permissible moisture content for manure mixed with hay, straw, wood shavings, or comparable bedding can be as high as 70% to 75% [2,3]. The relation between aeration and moisture content is further discussed in the section that follows.

2.3.4 Oxygen Requirements

Although in the 1940s and 1950s, anaerobic composting was regarded as a serious alternative to aerobic composting, modem composting strives to be essentially aerobic for many good reasons. Among the reasons are the assumed greater efficiency, reliability, and tolerance of shock conditions (e.g., sudden brief and drastic changes in environmental conditions), and the generation of fewer objectionable odours and other nuisances.

As is mentioned in the section on technology, aeration is accomplished through agitation (turning, tumbling, stirring), by forcing or drawing air through the composting mass, or through a combination of agitation and forced aeration. A variety of aeration rates is suggested in the literature. Among them are the following two: 1) 562 to 623 m^3/air non-volatile matter/day [6]; and 2) 263 to 306 mm^3/gram volatile solids/hr [7]. The rate at which sufficient oxygen to maintain aerobiosis is supplied is a function of the nature, and structure of the waste. Thus, the amount of oxygen required with a combination of easily decomposed waste and a large and very active microbial population would be much greater than would be required with a refractory waste and a small microbial population. Production of foul odours is a qualitative indication of insufficient aeration. Another excellent indicator is an unduly slow temperature rise in the active stage or an unexpected drop in temperature in later stages. Indicators less readily apparent, but more quantitative, are an unexplained slowing of rate of breakdown of organic matter, slowing of rate of oxygen consumption and carbon dioxide generation, and absence of expected physical changes in the composting mass.

In practice, the aeration rate should be determined by experimenting with the waste to be composted. If aeration is by turning, frequency of turning is the operational point of interest. With forced aeration, it is in terms of rate and volume of throughput air. Economic factors may force compromises in both areas. It is possible that composting could be accelerated by adding pure O_2 to the input air stream. However, the gain probably would not justify the sharply increased monetary expenditure.

2.3.5 Nutritional Requirements

For microbes, the macronutrients are carbon (C), nitrogen (N), phosphorus (P), and potassium (K). Among the micronutrients are cobalt (Co), manganese (Mn), magnesium (Mg), and copper (Cu). Calcium (Ca) falls between the macro and the micronutrients. Its principal role is as a buffer (resist changes in pH). Ideally, the waste should contain all necessary macro-and micronutrients. In practice, nitrogen probably would be the only nutrient that would need to be added. The occasion for adding nitrogen would be to bring an unfavourably high C/N ratio down to a more suitable level.

To be of use to the microbes, nutrients must be in a form that can be assimilated by them, i.e., is chemically available to them. Chemical availability to microbes is strictly a function of their enzymatic makeups or ability to synthesize enzymes as needed. Certain groups of microbes have the enzymatic complex or potential with which they can attack, degrade, and utilize the intact organic matter present in a freshly generated waste. Others can use as a source of nutrients only the intermediates that result from this attack, degradation, or utilization. The significance of this latter fact is that composting of a waste becomes the sum total of the collective activities of a dynamic succession of different groups of microorganisms in which one group serves as a precursor for succeeding groups.

Organic materials differ in their degree of resistance to microbial attack, in that some are readily broken down whereas others are resistant even when exposed to the required enzymatic complex. Moreover, breakdown of resistant materials advances slowly even under optimum environmental conditions. Examples of resistant substances are lignin (wood) and chitin (feathers, shellfish exoskeletons). Although readily available to many fungi, cellulose-C (in wood, straw, pith) is resistant to most microbes. Nitrogen is readily available when it is in the proteinaceous, peptide, or amino acid form. The small amounts of nitrogen in lignin and chitin are released too slowly for practical composting. Sugars and starches are readily decomposed, and fats are less so.

Experience has shown that with the exception of carbon and nitrogen, most organic wastes contain nutrients in the amounts and ratios required for composting [2,3]. Although less important than actual concentrations, ratios of certain nutrients to one another do exert an effect on microbial growth and activity. The most important of such ratios is the C/N ratio. The ideal ratio is about 20 to 25 parts of carbon to 1 of nitrogen (20/1 to 25/1). The composting process becomes increasingly slower as the C/N rises above this range. At high C/N ratios, microbes begin to immobilize nitrogen at the expense of microbial action. At C/N ratios lower than this range, nitrogen begins to be lost from the composting material as ammonium-N. A C/N ratio can be lowered by adding a nitrogenous waste (e.g., grass clippings, green vegetation, non-ruminant animal manure). Adding a carbonaceous waste such as hay, dry leaves, or chopped twigs, will raise a low C/N ratio of a waste such as sewage sludge.

2.3.6 Particle Size

With some justification, particle size could be validly regarded as a form of physical availability. In point-of-fact, it constitutes a limiting element in the expression of chemical availability. The justification for this claim arises from the role of enzymatic action in determining chemical availability. Because of that role, the larger the ratio of surface area of a particle to its mass, the greater is its exposure to enzymatic action, and hence, the more rapid becomes the rate of microbial activity and breakdown.

In theory, the smaller the particle size, the more rapid is the rate of microbial attack. There is, however, a minimum size ("minimum permissible particle size") below which maintenance of the porosity in the composting mass necessary for sufficient aeration becomes very difficult. With a rigid or not readily compacted material (e.g., fibrous materials, wood chips), the optimum size is from 5 to about 7.5 cm (2-3 in.). At the other extreme, the minimum particle size of the greater part of fresh green plant material (e.g., food wastes, fruits, lawn clippings), should be no less than 5 cm (2 in.). Depending upon the decomposability of the material, the maximum size can be as large as 15 cm (6 inches).

2.3.7 Mixing Requirements

To fully appreciate the importance of mixing and its functions in composting, it is necessary to keep in mind that for practical purposes, the microbes are not mobile. Therefore, the only environment encountered by each microbe is the exceedingly thin aqueous film by which it is surrounded. This film contains a mixture of: 1) dissolved nutrients; 2) nutrients in the colloidal state; 3) gases of atmospheric origin; 4) gases from metabolic processes; and 5) breakdown products released by the microbe. These breakdown products may be inhibitory or even toxic to the organism that synthesizes it. At the least they displace substances useful to the microbe, or they may bring about adverse changes in the immediate environment such as lowering the pH level. In short, the film is the sole source of nutrients and gases for the microbe and simultaneously is the repository for all of its products, both beneficial and inhibitory. Consequently, to ensure maximum, or at least adequate microbial activity, it is necessary to periodically renovate the immediate environments of all active microbes. The only way of doing this is by periodic mixing. Thoroughness and sufficient frequency of mixing constitute limiting factors.

With respect to composting, an outstanding benefit of mixing is its promotion of uniformity of decomposition. For pathogen control, it ensures the exposure, at one time or another, of all composting material to conditions lethal to pathogens. For aerobic composting, it renews the oxygen supply in the interstices between particles and removes accumulated carbon dioxide. An ancillary benefit is the promotion of loss of excess moisture. Of course, if moisture is limiting, this drying effect may be a disadvantage.

2.3.8 Hydrogen Ion Level (pH)

Usually, the pH level drops to about 5.0 as soon as composting conditions have been established. This initial drop is soon followed by a gradual rise that continues until a level of 8.5 is reached. Because of this sequence, buffering by adding lime ($Ca(OH)_2$) is not necessary. In fact, the addition of lime may lead to excessive loss of ammonia (NH_3-N). An exception might be in the composting of fruit wastes. With such wastes, the initial drop may be to 4.5. Liming, however, improves the physical condition (e.g., porosity, texture) of the composting wastes.

2.4 Approaches to Municipal, Commercial/Industrial, and Agricultural Composting

The basic principles and technologies described earlier can be applied to municipal, commercial/industrial, and agricultural composting operations. Major differences in composting these types of waste are the adaptations that are needed to compensate for the particular characteristics of the waste serving as substrate. Examples of such characteristics would be structure, lack of some macronutrient, or handling in general. Thus, these adaptations are mostly those made to accommodate the particular waste to the compost process.

The major sources of most compostable commercial/industrial residues are from the food processing, meat packing, and rendering industries. Each of these wastes varies in structure, nutrient content, etc. as do residues from agriculture and municipal solid wastes. A description of the adaptations and of variations between adaptations related to each of these wastes would be a major undertaking. Therefore, the remainder of this section deals mainly with the collection and storage of MSW, as composting is impacted.

Regarding municipal solid wastes, not all components are suitable as a substrate for the composting process. Moreover, the presence of the unsuitable components is both a liability in the composting process and also detracts from the utility or attractiveness of the compost product. Consequently, the compost process becomes more efficient and the quality of the product improves to the extent that these components are eliminated from the MSW. Separation of non-compostable components from the compostable components in MSW can take place before or after the MSW is collected. If separation takes place before collection, it is termed "source separation," and, if after collection, "post-collection separation." In short, freedom from non-compostables is a function of the manner in which MSW is treated at the point of generation, in storage, and in collection. (It should be noted that the advantages of source separation vs. post collection separation and the procedures involved, apply to all recyclable resources in the MSW.)

As is true in sewage sludge composting in general, the system usually proposed and applied in co-composting is the static pile. The present trend is towards enclosing the static piles in a shelter in order exert some control over the release of emissions into the environment. Another trend is towards in-vessel composting. The advantages and disadvantages of the two approaches as discussed previously also prevail in co-composting.

2.4.1 Municipal Wet/Dry Systems

2.4.1.1 Definitions and Classifications

The terms "wet" and "dry" refer respectively to the garbage (wet) and rubbish (dry) components of the waste stream. Until the late 1970s, the heading of this section would have been Separate Collection because the only form of source separation was that of refuse into garbage and rubbish. Thus, the separate collection of that day may be regarded as a rudimentary form of modem source separation.

2.4.1.2 Types of Storage and Collection Systems

Storage and collection are interdependent in that extent and type of separation in storage directly influences collection with regard to equipment and mode.

If no separation is done by the waste generators, all waste stream components are stored in single containers (combined storage), and hence are collected as such (combined collection). The combined refuse is then transported to a central site, where selected components may or may not be separated. Separation of this combined refuse constitutes post-collection separation.

In source separation, waste components are separated by the householder, and storage is adapted to maintain this separation. Various home storage containers designed to maintain separation are on the market and have been described in the literature [8]. The separated components can be collected simultaneously and kept separate by using a compartmentalized collection vehicle specifically designed for this function [9]. The separated components can also be collected separately. The frequency of collection must be suited to the nature of the particular components and the rate at which they are accumulated. Each approach (simultaneous collection and separated collection) has its particular advantages and disadvantages. Separation continues to be maintained at the treatment and disposal site. Among the many advantages of source separation are a greater freedom from contaminants, particularly heavy metals, as is indicated by the data in Table 2-2.

TABLE 2-2. Effect of Source Separation on the Heavy Metal Content of Various MSW Composts (Netherlands).

Element (ppm)	Type of Compost (Pre-Processing Method)			
	A	B	C	D
Cadmium	7	1.8	1.0	0.5 - 0.8
Chromium	180	40	30	50 - 60
Copper	600	100	50	26 - 37
Lead	800	420	160	41 - 67
Nickel	110	25	10	9 - 14
Zinc	1,700	520	230	140 - 210

A Raw MSW composted in windrows without any pre-processing. After composting (12 months), product is screened and inerts removed. [10]

B MSW shredded and mechanically processed to remove non-compostable material (i.e., glass, metals, plastics, etc.). Organic fraction composted. [10]

C Source Separation - Metals and other inorganic materials collected separately from organics. Organics composted. [10]

D Vegetable, fruit and yard wastes - Collected and composted separately from inorganics and paper. [11]

2.4.1.3 Wet (Garbage) Collection

The nature of garbage is such that the separate collection of the material is subject to many serious environmental and hygienic constraints that begin with its storage and continue through collection. In addition to being particularly odoriferous and unsightly, garbage attracts vectors and rodents. The strong attraction is due to the fact that it is a highly accessible and excellent source of nutrients for the pests, and also can serve as a shelter for rodents. Consequently, it is essential that garbage be isolated from the environment as completely as is possible. This isolation must begin with storage, continue through collection, and not end until treatment or disposal has been completed.

The storage container for garbage should be durable and easily cleaned. Most importantly, it must be have a close-fitting lid that is not easily displaced. The storage container and its contents should be protected from disturbance by domestic animals (dogs, cats) and be accessible only to the garbage collector.

As with storage, the collection of garbage should be such that exposure is minimal. Ideally, the collection vehicle should either be designed for garbage collection or it should be carefully adapted to that function. In particular, it should be water-tight and should be cleaned at the end of each run. Careful isolation and control must be continued during storage at the disposal site and throughout the subsequent disposal process.

Because garbage is so highly putrescible, ideally collection should be on a daily basis. Duration of storage at the disposal site prior to treatment or disposal should be minimal.

2.4.2 Variations on the Wet/Dry System

Variations on the wet/dry system range in extent from minor adjustments made to accommodate specific situations, to major changes that are discussed in the remainder of this section.

2.4.2.1 Recycling Centres

This variation calls for the generator to transport all or some of his or her separated recyclable wastes to a recycling centre. Items not transported to the centre are kept at the generation site and are collected later. An adaptation of this variation would be for the generator to transfer all recyclable wastes to strategically placed municipal collection bins for later transfer to a centre. This latter adaptation is being increasingly adopted in Europe. Yet another approach is for the householder to transport certain components of his or her wastes to a recycling centre, and leave the remaining components to be picked up by the collection vehicle.

The advantage of making the generator responsible for transporting some or all of the recyclable wastes is that it relieves the community of the responsibility and expense associated with it. On the other hand, its success is dependent upon the cooperation of householders.

2.4.2.2 Separate Collection of Yard and Garden Debris

This variation *calls* for the separate collection of yard wastes as a part of a municipal composting program. The term "yard and garden debris" is broad in that it includes not only wastes generated by householders, but also landscaping wastes (e.g., lawn clippings, leaves, herbaceous plants) generated at office complexes, in parks, on other municipal properties, etc.. The approach has gained a tremendous amount of popularity in the U.S., particularly in the Northeast.

2.4.2.3 Separate Collection of Yard and Food Wastes

This involves the collection of combined yard debris and food preparation wastes. Each of the two wastes, although separately stored, are later combined, either in the collection vehicle or at the treatment site. This variation might be loosely considered as being a version of co-composting, i.e., of yard wastes and food wastes. The practice is attracting favorable attention in Europe and Canada.

2.4.2.4 Co-Composting Yard and Food Wastes

The addition of food wastes to yard wastes not only broadens and intensifies constraints already on yard waste composting, it also adds constraints to counteract the undesirable environmental and hygienic impacts due to food wastes. These impacts were named and discussed in the section on wet garbage. Odour emission can be taken as an example. The odours associated with the normal storage and composting of yard wastes do not constitute a problem. On the other hand, the odour of raw garbage is objectionable to most individuals, and the objectionable nature persists until the material has been stabilized. Measures to be taken to comply with the constraints were also described earlier.

With respect to co-composting food wastes and yard wastes, probably the best approach would be to store and collect the two wastes separately. This is important because the storage and collection requirements for food wastes differ drastically from those for yard wastes. These reflect the wide difference between the physical and molecular natures of the wastes and their degradability, as well as between continuity of generation and volumes involved. Resorting to separate storage and collection postpones the time when the constraints peculiar to food wastes must be applied to the combined debris. Obviously, the task of ensuring proper isolation of the combined mass from the environment becomes more complex and onerous when the two wastes are finally combined for composting, e.g., stacked into windrows or introduced into the compost reactor.

The addition of food wastes to yard wastes does not lower the quality and utility of the compost product. In fact, in terms of quality, the product may be structurally and chemically enhanced, especially if the yard wastes had a sizeable concentration of woody material.

In summary, in terms of the compost process *per se*, the addition of food wastes to yard waste probably would have a beneficial effect. However, this benefit is not obtained without cost.

2.4.3 Post Collection Separation

Combined storage and combined collection continued to be the approach commonly followed until the 1980s. At that time, the interest in resource recovery resumed its current rate of expansion.

A basic step in the preparation of the raw material involves the separation of the compostable from the non-compostable fraction. For yard and food wastes collected separately from MSW, this step would involve manual sorting. For MSW, the ideal in terms of achieving highest efficiency for segregation would be to carry out the primary separation at the household level (pre-collection separation).

Post-collection separation is for the most part done mechanically, although some manual sorting may be employed. Mechanical separation is accomplished in a series of unit processes. Chief among these unit processes are size reduction, screening, air classification, and magnetic separation. Basic principles and technologies are described in considerable detail in the literature [3,15,16].

2.4.3.1 Size Reduction

Of the many types of size reduction equipment the two most commonly used for MSW are the hammermill and the grinder, with the hammermill being the more common of the two. Basic types of hammermills are the vertical-shaft and the horizontal-shaft. The operating principles for both types are quite similar, With a vertical mill. particle size can be controlled by changing the spacing between hammers and housing; whereas with a horizontal hammermill, it is accomplished by means of grate bars.

The most commonly used type of grinder is the ring grinder. The ring grinder basically differs from the vertical hammermill in that the grinder has grinding wheels rather than hammers. The refuse is ground by the action between several free-floating grinding wheels and a series of fixed bars protruding from the shell of the machine. Particle size is controlled by adjusting the spacing between grinding wheels and a choke ring. No grate bars are used.

For particular applications, optimization of the performance of the size reduction process can be directed to one or more of the following: feed rate, size distribution, wear, and power consumption. Certain interrelationships, and particularly their bearing on cost, should be kept in mind when optimizing the process. For example, optimization directed at particle size has a major effect on the overall cost of the size reduction operation. The reason is that energy consumption and equipment wear-and-tear increase in direct proportion to extent of reduction in particle size [17,18]. Thus, specific energy consumption (net energy [kWh]/tonne size reduced) increases sharply at characteristic particle sizes smaller than 0.75 cm (0.3 inches); whereas it is relatively modest at particle sizes larger than 2.5 cm (1 inch) [18]. ("Characteristic particle size" refers to the size of the screen openings through which 63.2% of the particles can be passed.)

As with energy consumption, wear-and-tear of the hammers increases sharply with reduction in characteristic particle size distribution. Hammer wear becomes especially high as the characteristic particle size drops below 0.75 cm (0.3 inches).

2.4.3.2 Air Classification

Basically, separation is accomplished in an air classifier through the interaction between a moving air stream and the material introduced within a column. Refuse components characterized by a large drag-to-weight ratio tend to be suspended in the air stream. They constitute the air-classified light fraction. Particles that have a small drag-to-weight ratio (e.g., metals, glass, fines) tend to settle. Not surprisingly, they make up the air-classified heavy fraction.

Existing air classifier designs can be broadly classified into vertical, horizontal, and inclined. The air stream moves vertically through the classifier column in the vertical version. Vertical classifiers differ among themselves; some may be provided with baffles (zig-zags).

The air classifier split can be expressed as the ratio of the light fraction to the heavy fraction. The split is influenced by several variables, namely, air-to-solids-ratio, column velocity, refuse moisture content, particle size distribution, and column loading. Generally, the present opinion is that overall performance improves until the column loading factor approaches 7 Mg/hr/m^2 (0.7 ton/hr/ft^2). Loadings higher than this do not further enhance performance. On the other hand, separation is not significantly improved by lowering column loading to less than 5 Mg/hr/m^2 (0.5 ton/hr/ft^2) [19].

2.4.3.3 Screening

Particles may be effectively separated into two or more size groups by the use of a screen. In such a separation, the size group having a minimum particle size larger than that of the screen openings stays on the screen and is known as the oversized fraction. The second size group passes through the openings and is known as the undersize fraction.

A list of important screening parameters would include screening efficiency, residence time, bed depth, critical frequency, screen capacity, screen loading, length-to-diameter ratio (trommel screens), and screen performance. Efficiency relates to the ratio of undersize material actually removed by the screen to the total amount of that material in the feed material. Therefore, it constitutes a measure of the degree of separation of materials based on particle size. Efficiency attained in a given situation is a function of the physical properties of the input material, degree of agitation imparted to the material while on the screen surface, depth of the material on screen surface (bed depth), and residence time on the screening device.

The surface area of the screen should be large enough to allow a sufficiently long residence time (average length of time on a screening surface or inside a trommel screen), and yet permit the depth of the bed of refuse on the screen to be sufficiently thin. Meeting this two-fold requirement necessitates a very large surface area when high-volume materials such as paper and plastics are major components of the feed material.

Types of Screens

Screens may be classified into two broad groups: flat-bed screens and cylindrical screens. Among the principal types of flat bed screens are vibrating, reciprocating, and gyrating. The only type of cylindrical screen is the trommel. The types most commonly found in the waste processing industry are the vibratory flat bed screen, the disc screen, and the trommel screen. Whereas experience with flat bed screens has been less than successful, that with the trommel screen has been quite successful in terms of effectiveness and efficiency [15].

- Flat Bed Screens

  The vibrating flat bed screen is used in waste processing for separating fine particles. The vibratory motion of the screen enhances its efficiency by: 1) increasing the number of particles that come in contact with its surface; 2) reducing the incidence of entrapment of small particles; and 3) prolonging residence time. A limiting factor on efficiency is the depth of the material on the screen surface. Permissible depth varies with length of residence time.

  The reciprocating screen is a type of vibrating screen. Its action is a rocking motion, end-to-end, in which the screen is on an incline and the housing is on springs. A disadvantage of the reciprocating screen is the frequency of spillage. Moreover, the significant screen wear associated with the vibration can lead to other problems.

  The gyrating screen, another version of the vibrating screen, pivots at one end of its housing. Chances for spillage from a gyrating screen are lower because the particles never leave the screen surface.

  The disc screen is a third version of the vibrating fiat bed screen. It consists of a series of discs attached to small-diameter shafts in parallel configuration. The discs from each alternating cylinder complement each other. As the cylinders rotate, objects of small size pass through the length of the screen.

- Cylindrical Screens

  The trommel screen is a rotary cylindrical screen, the screening surface of which may be either a wire mesh or a perforated plate. In some operations, incoming waste is passed through a trommel before being size reduced (pre-trommeling). In others, the trommel screen is used after the waste has been size reduced (post-trommeling). Some operations have both pre- and post-trommeling [20].

  Extensive usage has shown the trommel screen to be a particularly efficient device for screening waste. Its efficiency comes from the tumbling to which it subjects throughput material. Because it combines a high degree of screening efficiency with a minimum of screening surface, tumbling is very effective for screening municipal solid waste The general experience has been that with respect to screening municipal solid waste, trommeling surpasses all flat bed screens.

  The size of a trommel screen's openings can be arranged such as to direct particular municipal waste components either into the oversize fraction or into the undersize fraction. If the component size distribution of refuse is known, the effect of a given screen mesh on the final size distribution of each component after screening can be determined.

Four important design and screen performance parameters specifically applicable to trommels are critical frequency, screen loading, length-to-diameter ratio, and angular velocity. Critical frequency is that frequency of rotation at which material in the trommel is held by centrifugal force against the screening surface through an entire revolution. With respect to screen loading, screening efficiency remains fairly constant until an overload condition is approached. Typical length-to-diameter ratios for raw refuse and the screened air-classified light fraction range from 2:1 to 5:1. Angular velocity determines particle motion and associated velocity of material along the axis of the screen. The relation varies with screen geometry and inclination.

2.4.4 Home Composting

2.4.4.1 Specific Biological Principles

The basic biology of home composting is the same as that described earlier. However, the manifestations and corresponding responses in terms of procedure with home composting may differ somewhat from those appropriate for other composting applications. For example, in home composting, the heat retention capacity (self-insulation) of the composting mass has a much greater influence on the rise of temperature level in the interior of the composting mass than it has in larger-scale operations. The smaller the mass, the lower is the self-insulation capacity. Thus, for temperatures to reach levels lethal to human, livestock, and plant pathogens, the volume of the composting material must at a minimum be approximately 1 m^3 (3.3 ft^3) The volume would be slightly less with a less porous mass and more with a very porous mass, especially if the mass is exposed to high winds. The lethal temperature for plant pathogens and weed seeds is on the order of 70°C (see Figure 2-2). Lethal temperatures for most human and animal pathogens are in the range of 50 to 65°C, with the exception of the more resistant forms (e.g., spores, conidia, ova) which can require temperatures in the range of 70 to 80°C for inactivation. Consequently, failure to reach lethal levels could lead to a reinfection of ornamentals and food plants if the householder were to return the compost product to the garden.

2.4.4.2 Methods and Equipment

Because the usual site of a home composting operation is in a residential area, the generation of objectionable odours in the composting mass must be carefully avoided. Because objectionable odours almost invariably are generated as a result of the onset of anaerobiosis in the pile, the best preventive as well as remedial measure is adequate aeration. Needed aeration is most simply attained by increasing the turning frequency. An added advantage of increasing the turning frequency is the acceleration of composting rate. For example, with a substrate consisting mostly of herbaceous plant debris (i.e., little or no shrubbery), required retention time to produce a fully composted product may be as brief as 12 days at a turning frequency of one turning every other day (a total of three turnings), and as long as 30 days with turning as once per week. If frequent turning is infeasible, then an odour problem may be alleviated by covering the material with a thin layer of soil or of fully matured compost.

Equipment is largely a matter of the personal preference. For the compost enthusiast, it can border on the elaborate, e.g. a chipper for brush, a grinder for herbaceous debris, and even a prefabricated "reactor."

Unless the composting is done in a rural setting, an open pile is to be avoided and a bin should be used. The bin may be constructed of concrete, wood, or even of hardware cloth. Floor dimensions should be at least 1 x 1 m (3.3 x 3.3 feet). The height can be from 1 to 2 m (3.3 to 6.6 feet). The bin should be constructed such that one side can be removed to provide easy access to the composting mass. If hardware cloth is used, the mesh size should be 6 mm (0.25 inches), and the wire should be of heavy gauge. Obviously, the cloth should be attached to a sturdy frame. An advantage in the use of hardware cloth is that all surfaces of the composting mass are exposed to air. Disadvantages are: 1) the same exposure becomes a detriment in the event of a fly problem; 2) durability does not match that of concrete or wood; and 3) there is little protection against heat loss.

A double bin (adjacent bins sharing one common wall) has certain advantages. For example, one bin could serve as the reactor, while material for a second run could be accumulating in the second bin. To meet local health regulations, the exposed surface of the composting material should be covered with a fly-proof screen.

A five-tined pitchfork is an excellent tool for turning the material, because it facilitates the desired fluffing of the material. Manipulation of a conventional manure fork is awkward. Turning by way of a shovel would be more difficult and less effective than with a fork.

2.4.4.3 Constraints

An important constraint on home composting pertains to the substrate. For example, the use of meat wastes as a substrate constituent in home composting is conducive to the development of nuisance problems. Not only does the meat become malodorous, it is a strong attractant for vectors and rodents. Although it is true that these problems disappear as the compost process advances, an appreciable time intervenes. Many health regulatory agencies have rules against the use of meat waste as a substrate. If it is nevertheless used, strong countermeasures should be taken.

Another constraint regards siting the compost bin. The location on one's property should not be where it would interfere with a neighbour's enjoyment of his property. In other words, it should be some distance from property boundaries.

Other constraints pertain to convenience and feasibility. One such constraint comes from spatial requirements that for the most part limit home composting to single-family residences. Even with single-family residences, dedicating any space to composting may not be possible. Granted that space is available, proper conduct of a home composting operation demands a considerable dedication on the part of the homeowner, and must compete with other demands for time. After all, whether or not the operation becomes a source of nuisances and even of health problems is a function of the dedication had by the operator.

2.4.5 Co-Composting

Co-composting may be broadly defined as "composting a mixture consisting of two or more types of wastes." Examples of such mixtures are manures and crop residues, manures and MSW, industrial food processing waste and MSW, and MSW and sewage sludge. Because the reference in the modem literature usually is to the MSW/sewage sludge mixture, "co-composting" is used in that sense in *this* section, unless otherwise specified.

In common with other forms of composting discussed in the preceding sections, co-composting is not a recent development. In fact, in almost all of the early attempts at demonstration and full-scale application of MSW composting, the usual procedure was to add sewage sludge in some form to the MSW. The purpose of the addition was not so much to treat the sludge, as it was to supply needed moisture and to enrich the MSW with nitrogen and phosphorus. Although the practice of co-composting in the U.S. gradually waned during the 1970s, it continued unabated in western Europe. In fact, the loss of interest in the U.S. was not confined to co-composting; it also applied to MSW composting. It was not until after the phenomenal surge of sewage sludge composting in the early 1980s, that interest in MSW composting began to revive. The revival was triggered mainly by the possibility of MSW serving as a bulking agent in sewage sludge composting. Not to be overlooked, however, is another recent development that has intensified the revival, an increasing consideration of composting of MSW as an alternative to incineration.

The generic biology and parameters of co-composting are identical with those for composting in general. Adaptations in technology are those made in response to the sludge fraction of the mixture. For the most part the adaptations relate to developing procedures for thoroughly mixing the sludge and MSW without promoting clumping and other phenomena that lead to significant loss of porosity. Equipment for accomplishing such mixing is appearing on the market.

The need for adaptations in technology arises from the shortcomings of MSW as a bulking agent. These shortcomings are traceable to the high paper content of typical MSW. As is common knowledge, the "structural strength" of paper drops with rise in moisture content. Consequently, the tendency of a mixture of sludge and paper is to compact. (The significance of structural strength with regard to moisture content and aeration was discussed earlier.) Moreover, the morphology of shredded paper particulates is not conducive to pore formation, i.e., interstices are flattened in shape and their volumes are small. Furthermore, paper fibers have a tendency to mat, and this tendency intensifies with increase in moisture content. A disadvantage as a bulking agent, but a distinct advantage as a microbial substrate, is the susceptibility of the cellulose fraction of paper to microbial attack and subsequent assimilation of the carbon thus released. However, the loss of bulking agent is more than counterbalanced by the destruction of a sizeable portion of the MSW output.

One of the more serious problems confronting co-composting of sewage sludge and MSW is the serious constraints made on the use and also on the disposal of the co-compost product. Problems and constraints that apply to sewage sludge compost and to MSW compost also apply to the co-compost product. Underlying these constraints are the heavy metal and toxic or otherwise hazardous organics contributed to the product by the sewage sludge fraction of the mixture. In Europe, the contribution is great enough to sharply restrict usage of the co-compost product. Concentrations of toxic substance in sewage sludge and MSW could be considerably reduced through the imposition of strict standards on effluents discharged by industry and communities into the community waste streams. With respect to MSW, careful control of household hazardous wastes would be a distinct advance.

In 1980, the Ontario Ministry of Agriculture and Food (OMAF) and the Ontario Ministry of the Environment (MOE) agreed to conduct research on the utilization of composted materials on agricultural land [21].

A five year study was conducted to investigate the effects of composted sewage sludge from Windsor and composted paper waste from Toronto on the growth and yield of corn grown in two soil types. The composts were applied only once at rates of 55, 111, 165 and 220 tonnes per hectare. The organic matter level in the clay loam soil increased with increasing amounts of compost applied. Organic matter levels increased on the sandy loam soil when the Toronto compost was applied. Levels increased using the Windsor compost only at the 220 t/ha loading.

The soil phosphorous (P) levels increased with increasing rates of the Windsor compost on both soil types. The Toronto compost increased P levels only in the clay loam soil. The potassium and magnesium levels remained the same in both soils.

Corn growth and yield was unaffected with one exception. The corn showed marked phytotoxicity and lower yields in the year that the uncured composted paper waste was applied to the clay loam soil.

The compost had no effect on the heavy metal levels of the corn leaf and grain. Levels of copper and nickel in the soil were slightly increased by the compost additions.

2.5 References

[1] Golueke, C.G., Composting, Rodale Press, Inc., 110 pp., 1972.

[2] Golueke, C.G., Biological Reclamation of Solid Wastes, Rodale Press, Inc., 249 pp., 1977.

[3] Diaz, L.F., G.M. Savage, and C.G. Golueke, Resource Recovery from Municipal Solid Wastes. Vol. II. Final Processing, CRC Press, Boca Raton, Florida, 178 pp., 1982.

[4] Golueke, C.G. and L.F. Diaz, "Starters -- Inoculums and Enzymes," BioCycle 30(4):553-557 (April 1989).

[5] Golueke, C.G., "A Critical Evaluation of Inoculums", Applied Microbiology, 2:45-53 (1954).

[6] Shulze, K.F., "Rate of Oxygen Consumption and Respiratory Quotients During the Aerobic Decomposition of Synthetic Garbage", Compost Science, 1:36 (Summer 1960).

[7] Lossin, R.D., "Compost Studies: Part III, Measurement of Chemical Oxygen Demand of Compost", Compost Science, 12 (March/April 1971).

[8] Glenn, J., "The Transition of Home Storage Containers," BioCycle, 30(6):45-51 (June 1989).

[9] "Collection Vehicles Hit the Road," BioCycle, 30(6):37-39 (June 1989).

[10] Oosthoek, J. and J.P.N. Smit, "Future of Composting in the Netherlands, BioCycle, 28(6):37-39 (July 1987).

[11] Lustenhouwer, H.W.A., F.A. Reijenga, and H.C. van Weenen, "Source Separation and Collection of Household Compostables," BioCycle, 28(6):33-36 (July 1987).

[12] Diaz, L.F., G.M. Savage, and C.G. Golueke, Resource Recovery from Municipal Solid Wastes. Vol. 1. Primary Processing, CRC Press, Boca Raton, Florida, 166 pp., 1982.

[13] Savage, G.M., J.C. Glaub, and L.F. Diaz, Unit Operations Models for Solid Waste Processing, Pollution Technology Review No. 133, Noyes Publications, 214 pp., 1986.

[14] Processing Equipment for Resource Recovery Systems, Vol. III -- Field Test Evaluation of Shredders, Final Report prepared by Cal Recovery Systems, Inc. for U.S. EPA, Report No. 600/2-80-001, 1980.

[15] Savage. G.M., J.C. Glaub, D.J. Lafrenz, and L.F. Diaz, Engineering Design Manual for Solid Waste Size Reduction Equipment, U.S. EPA Report No. EPA-600/SB-82-c, 1982.

[16] Savage, G.M., L.F. Diaz, and G.J. Trezek, "Performance Characteristics of Air Classifiers in Resource Recovery Processing", Proceedings of Ninth National ASME Waste Processing Conference, May 1980.

[17] Land Treatment of Hazardous Wastes, Ed. J.F. Parr, P.B. Marsh, J.M. Kla, Noyes Data Corporation, 422 pp., 1983.

[18] Comprehensive Studies of Solid Waste Management, SERL Report No. 69-1, Sanitary Engineering Research Laboratory, University of California, Berkeley, 245 pp., 1969.

[19] Comprehensive Studies of Solid Waste Management, SERL Report No. 72-3, Sanitary Engineering Research Laboratory, University of California, Berkeley, 166 pp., 1972.

[20] Decomposition of Toxic and Nontoxic Organic Compounds in Soils, , Ed. Mr. M.R. Overcash, Ann Arbor Science Publishers, Inc./Butterworth Group, 455 pp., 1981.

[21] Dalzell, H.W., A.J. Briddlestone, K.R. Gray and K. Thurairajan, Soil Management: Compost Production and Use in Tropical and Subtropical Environments, FAO Soils Bulletin 56, Rome, 1987.

[22] Baldwin, C.S., C. Nanni and M.A. Nuttall, Compost Utilization and Corn Production in Southwestern Ontario, Ministry of Agriculture and Food Ontario Report, 1989.

3.0 DOCUMENTATION OF EXISTING COMPOST TECHNOLOGIES

3.1 Introduction

A generic description of the composting process, types of processing technologies, operating and control parameters, and applications *was* the focus of Section 2. In this section, the emphasis turns from a general textbook-type description of the process to a presentation of information on existing composting practices. Descriptions of various composting systems are presented to demonstrate the technologies being practised. The remainder of the section is devoted to a discussion of the economic and marketing aspects of composting.

It is important to mention at this time that much of the information presented in the following sections was extracted from promotional literature developed by the system vendors and, therefore, may be somewhat biased. All of the costs in this section are in Canadian dollars.

3.2 Internationally Available Technologies

As discussed in Section 2, compost technologies can be broadly divided into four groups: turned windrow, static pile, in-vessel, and hybrid (which is a combination of technologies). In the sections that follow, descriptions are provided for compost systems that fall into each of these categories. Appendix B provides a partial list of vendors and facilities. The systems described are representative of those currently on the market. The following systems are discussed:

Turned windrow	Agripost, Inc.
	Ecological Technologies (ECOTECH), Inc.
	Environmental Recovery Systems, Inc.
	Compost Management Associates Ltd.
Static pile	Buhler-Miag, Inc.
	Daneco
	WPF Corporation
In-vessel	American Bio Tech, Inc.
	American Recovery Corporation
	Ashbrook-Simon-Hanley
	Bedminster Bioconversion Corp.: The Eweson Process
	Compost Systems Company (Paygro and Dynatherm)
	Ebara Environmental Corp.
	Fairfield Service Company
	International Process Systems
	OTVD Group Energies
	PURAC Engineering, Inc.
	Recomp
	Royer Industries
	Taulman Composting Systems
Hybrid	California-Co-Composting Systems
	Harbert/Triga International, Inc.
	Waste Processing Corporation (Dano)

3.2.1 Turned Windrow

3.2.1.1 Agripost

The Agripost system was originally developed and implemented over 30 years ago. The two projects in the 1950s included one in McKeesport, Pennsylvania and the other on the island of Jamaica. Today the system is being marketed by Agripost Inc. in Pompano Beach, Florida. The company is in the process of building an 725 tonne/day MSW processing facility to process part of the waste generated in Dade County, Florida. Final testing of the plant is expected to be completed by November of 1989. Initially, the facility is expected to produce representative end-products for testing and for marketing.

Feedstocks

The Agripost process treats mixed municipal solid waste. Agripost's description of its system indicates that it is capable of treating 100% of the incoming waste stream [1-4].

Description of Operation

All of the processing and composting is conducted inside of buildings. According to the vendor, the system works as follows: waste is discharged on the tipping floor, non-processible materials are removed, and the remainder of the waste is conveyed into two stages of size reduction. The ground waste is inoculated with a bacterial enzyme to expedite the decomposition process. The inoculated material is transported to an adjacent building and formed into windrows for composting. The piles are turned periodically depending upon temperature and moisture content. The active bacteria in the pile is capable of degrading all organic materials. Heat produced by this action creates an oxidizing effect on metals, plastics, and other hard "inorganic" constituents. After four weeks of active composting, the material is conveyed to a tertiary stage of size reduction. After shredding, the compost is screened. The oversize items are returned to the composting process. The undersize is ready for marketing. The company claims that the inorganics are broken down into an oxide form and become part of the fertilizer [1-4].

Agripost offers to either own and operate a facility, or to sell the plant to the customer. The company will not, however, turn over the actual operation. Agripost requires that provisions be made to operate the plants, maintain ownership of the product, and maintain the responsibility for distributing the compost.

3.2.1.2 Ecological Technologies

Ecological Technologies, Inc, (Ecotech), was founded approximately two years ago. Ecotech is one of the few vendors that has an operating MSW compost facility in the United States. The plant is located in Sumter County, Florida. The facility began operating in the summer of 1988. Ecotech has the exclusive license to market the process developed by U.S. Waste Recovery Systems. The technology is known as the "BDX Process."

Feedstocks

The plant operating in Sumter County currently processes about 100 tons of mixed municipal solid waste per day.

Description of Operation

The processing system can be described as follows: MSW is discharged on the tipping floor. Oversize and hazardous materials are removed from the feedstock. The remainder of the refuse is conveyed into a flail mill. The mill tears open bags and other containers. The milled refuse is then conveyed past a magnetic belt for removal of ferrous metals. After magnetic separation, the material is hand sorted to remove aluminum, glass, paper, plastic, and cardboard. After hand sorting, the material is conveyed into a shredder. The shredder size reduces the material to particles 2.5 to 5 cm in size. It is reported that the hand sorting operation and the magnetic separation recover a minimum of 25% of the recyclable materials.

The shredded material is loaded onto small dump trucks and transported to the composting pad. The composition of the composting feedstock is between 50% and 75% paper and vegetative waste, and about 25% plastic, metals, wood, etc. The refuse feed is formed into windrows and aerated mechanically. The compost turner is equipped with nozzles for maintaining the proper moisture content and adding a proprietary formula of enzymes and bacteria. The inoculum is added for the purpose of accelerating waste decomposition.

After the material is composted, it is air classified and screened. The screen is an auger type with graduated 2 to 2.5 cm openings. Ecotech has been considering the use of a trommel screen for final processing. Residuals from the process are estimated at about 5% to 10% of the incoming waste stream [5-7].

Markets

The County has a number of interested potential end-users such as local citrus growers and nurseries. The County is, however, waiting to start actual marketing activities until tests on the end-product are completed. In other projects, Ecotech expects to explore the potential of using the compost for horticultural and agricultural uses. Other markets under consideration include international export markets and reclamation of marginal lands [5-7].

Economics

It has been estimated that the capital cost of the facility in Sumter County, Florida was on the order of $4.1 million. Ecotech contributed $1.8 million and the County the remainder. It has been reported that the tipping fee at the facility is U.S. $20.75/tonne [7].

3.2.1.3 Environmental Recovery Systems

Environmental Recovery Systems (ERS) was established in 1986. ERS is planning an MSW facility in New Milford, Connecticut [8]. The system for the New Milford facility was designed by ERS and evaluated by Morrison-Knudsen Engineers, Inc. The project team for the facility includes ERS, MK-Environmental Services (for design and construction management), and CH2M-Hill (for environmental and permitting support).

Feedstocks

The facility planned for New Milford is designed to recover over 90% of the municipal solid waste stream [8].

Description of Operation

The processing facility functions as follows. Municipal solid waste is discharged onto the tipping floor where sorters open bags and remove unacceptable items. Non-processible materials are sent to the landfill for disposal. The waste is pushed into a conveyor belt and transported to a trommel screen. The trommel separates the waste into two fractions. The fine waste fraction (primarily organic mailer such as leaves, grass, and food, as well as some dirt) is conveyed over a magnetic head pulley to remove ferrous metals. The remainder is transported to the composting area. The oversize fraction from the trommel is conveyed to a sorting room. In the sorting room workers remove recyclable items. The rest of the oversize material is shredded and screened.

The smaller particles are taken to the composting area. The large paper fraction is removed and baled. The feedstock to the composting process is placed in windrows, which are mechanically fluffed and aerated. After a period of 28 days, the compost is sampled and tested in a laboratory. Once specifications are met, based on local regulations, the compost is placed in curing/storage piles.

The process is designed to produce compost and to recover corrugated cardboard, paper products, ferrous metals, plastics, glass, aluminum, and other non-ferrous metals. ERS's informational proposal [8] indicates that the process requires no incineration and no landfill. The average size of an ERS system would be 635 tonnes/day [8-9].

3.2.1.4 Compost Management Associates Ltd.

Compost Management Associates Ltd. of Toronto and Organic Recycling Inc. of New York, draw on more than 12 years of direct experience in the hands-on management of composting sites. Compost Management plans and sets up the composting program, provides ongoing training for site staff and supervises all critical operations. The municipality provides the land, equipment and equipment operators.

Feedstocks

Compost Management have experience in composting agricultural waste and leaves, and have integrated other organic materials such as grass clippings, mixed yard wastes, chipped brush and residential food waste.

Description of Operation

Compost Management ensures that the municipality retains complete control of the composting operation while providing experience and technical expertise. Site design and management are flexible to accommodate local conditions, climate, management objectives and seasonal equipment availability.

3.2.2 Static Pile

3.2.2.1 Buhler-Miag

Buhler-Miag is a subsidiary of Buhler Brothers Ltd. of Uzwil, Switzerland. Buhler-Miag primarily is an equipment manufacturer having a Canadian office in Toronto, Ontario. The company has designed and provided equipment for about 100 processing plants throughout the world. The plants range in capacity from approximately 36 to 2,700 tonnes of waste per day. Until recently, Buhler's resource recovery system was marketed in the United States by Reuter, Inc. of Minnesota. In November 1988, its agreement with Reuter ended. Shortly thereafter, Buhler entered into an agreement with Wheelabrator

Technologies, Inc. of Danvers, Massachusetts, in which Wheelabrator is made the distributor of Buhler-Miag's front-end solid waste processing, recycling, and composting systems in the United States.

Representatives from Wheelabrator indicate that the systems will either be: 1) integrated into its new waste-to-energy projects; 2) installed in some existing facilities; or 3) sold separately for centralized processing facilities. Initially, the composting component of the Buhler system will be used by Wheelabrator as part of its integrated "Recycle First" program.

Feedstocks

Capacities for the Buhler-Miag system range from about 45 to 635 tonnes/day of municipal solid waste. Initially, the composting components of the Buhler system will be used by Wheelabrator for leaves and yard waste.

Description of Operation

The processing line includes handsorting, magnetic separation, air classification, size reduction, and screening. The material is composted in aerated windrows. Additional aeration is accomplished by means of a windrow turning machine. After composting, the material is conveyed to a processing area where it is run through additional size reduction and fine screening. The screening process is designed to remove plastic, paper and woodchips. The refined compost then goes to a ballistic separator and a magnetic belt for the removal of glass particles, stones, and ferrous metals. The finished compost can be ground once more depending upon the specifications for the particular end uses [10-12].

To date, there is no Buhler-Miag MSW composting system operating in North America.

3.2.2.2 Daneco

Daneco is an Italian corporation which has ten commercial-scale MSW composting projects overseas. Six facilities currently are under operation and three are at various stages of construction. The capacities of these facilities range from about 54 to 600 tonnes of MSW per day. In the U.S. Daneco has been selected to implement a 154 tonnes/day MSW composting plant in Southold, New York, pre-qualified for a 180 tonnes/day composting facility in Hennepin County, Minnesota, and is one of two finalists to build a 435 tonnes/day material recovery and composting plant in San Diego, California [13].

Feedstocks

The Daneco system is designed to process mixed municipal solid waste. Sewage sludge can be added to the MSW feedstock prior to composting. The Daneco system can be used for composting facilities in the range of 45 to over 900 tonnes/day.

Description of Operation

A typical design for a Daneco facility is as follows. Waste delivered by collection vehicles is discharged on the floor of a receiving area. Non-processible wastes are identified and removed. Processible waste is conveyed into a shredder. After size reduction, the material is conveyed past a magnetic belt for the recovery of ferrous metals and into a trommel screen. The trommel separates the stream into two fractions. The oversize fraction is taken to the residue storage area. The undersize is taken to a secondary trommel screen for additional processing. The secondary trommel recovers an oversize fraction that is relatively free of high density materials and an undersize fraction that contains both organic matter and inerts. The undersize is transported to a wet system for removal of the inert matter.

After separation of the inert matter, the organic fraction is mixed with the oversize fraction. The entire mixture is transported to the composting area.

At the composting area, the feedstock is formed into windrows. The windrows are aerated by means of air distribution channels located in the floor. After the composting process is completed, the material is cured. Prior to marketing, the finished compost is processed through a lump shredder and a screen for refining. The overall system can be modified to also produce a refuse-derived fuel, either fluff or densified. The inert matter recovered from the wet separator can be, after magnetically removing the ferrous metals, used as an aggregate for construction activities [5].

Daneco has a North American subsidiary, Daneco Inc., in New York City.

3.2.2.3 WPF

The company offers a system that is totally under cover. The company is in the process of building two processing facilities, one with a capacity of 180 tonnes/day and the other, 680 tonnes/day. The facilities are scheduled to begin operation at the beginning of 1990 [14].

Feedstocks

The two facilities being built by WPF will process mixed municipal solid waste. After recyclable materials are recovered, sewage sludge can be added to produce a co-compost product. The capacity of the system ranges from 45 to 1,100 tonnes per day [15].

Description of Operation

According to information provided by WPF, the system consists of a series of modules for the recovery of recyclable materials and compost. In the process, the waste is deposited in the tipping area. Oversize items, tires, and other materials are removed on the tipping floor. Non-processible materials are also removed and taken to a landfill. The compostable material is processed through two stages of size reduction. A magnetic belt removes the ferrous metals. Finally, the shredded material goes through a flail/homogenizer.

The MSW feed can be mixed with sludge and then put into windrows. The windrows are aerated by means of vents placed on the floor. In addition to forced aeration, the windrows are turned every three days by means of a windrow turning machine.

The composting system can recover up to 95% of the incoming waste stream. The active composting process is claimed to require 17 days. After composting, the material is processed through a flail mill for additional size reduction and then through a 0.64 cm. trommel screen. Other unit processes such as air classification can be added as required. The compost is then allowed to mature for a period of 45 days in an aerated, covered area [14-15].

3.2.3 In-Vessel

3.2.3.1 American Bio Tech

Feedstocks

Materials treated by this technology include dewatered sludge solids and an amendment (sawdust). Proportional amounts of dewatered sludge, amendment, and recycled compost are mixed to the targeted content of 35% dry solids [16].

Description of Operation

A conveyor moves the feedstock mixture to the reactor train. This mixture is deposited on top of the bioreactor, but only after the following operations are completed: 1) one layer **of** finished compost is removed from the bottom of the curing cell and either stored for shipping and sale, or recycled as needed; and 2) a layer of mixture is removed from the bottom of the bioreactor and is transferred to the top of the cure reactors, making room for a fresh mixture of dewatered sludge and amendment on top of the bioreactor [16].

The movement of material through the system is accomplished by a large take-out screw which traverses the entire length of the bottom of the bio and cure reactors. Approximately 61 cm. of product is removed each pass. Loading and unloading functions can be carried out on a continuous basis without process interruption. According to the vendor, this reduces the occurrence of anaerobic, odorous conditions [16].

Aeration is accomplished through the use of an air manifold coupled to vertical lances positioned throughout the compost mass. The manifold system is positioned near the top of the containment structure. Every other manifold is designed to alternately deliver air to or evacuate air through the lances, thus creating a shortened horizontal airflow path between the rows of lances.

The purpose of the reduced air path is a lower pressure drop and subsequently, lower energy consumption. The low pressure allows the use of industrial fans instead of high pressure positive displacement blowers. In addition, according to the vendor, the shortened air path decreases the possibility of the air short-circuiting and causing anaerobic pockets within the composting mass.

Each lance utilizes an internal air profile insert and partitions to assure an even, controllable airflow profile over its entire length. The design is intended **to** compensate for increased density in the lower section of the reactor. The air profile insert is field changeable to allow modifications to the airflow profile [16].

The process is controlled by varying airflow rates which adjust temperature to attain the maximum biological rates, stabilization, and drying within the bioreactors and cure reactors. The control system provides trend information to facility operators, thereby allowing control of airflow rates to be based on trend rather than point changes in the measurements. Reactor temperatures are recorded for this purpose. Airflow rates are shown on an indicator meter next to each blower and in the instrument control room where they are recorded. Temperature probes are installed in each reactor for continuous monitoring of reactor temperature profiles. Automatic operation of on/off loading sequences are activated by operator control buttons [16].

Duality Control Parameters

The ABT process provides 14-day bioreaction and curing stages, both taking place in fully enclosed, odour controlled structures. The reactors are totally enclosed and designed to maintain a negative pressure. The negative pressure serves two purposes: to reduce the amount of moisture and odours within the building enclosure and to ensure all odours are contained. All exhaust air from the reactor building considered to be odorous is treated by a multi-stage odour control system consisting of: 1) heat exchanger for condensing particulates; 2) wet scrubber for condensation and odour particles; 3) two-stage chemical reactor tower, and 4) adequate retention time for chemical reaction [16].

Problems with high noise levels from fans are kept to minimal levels by the following two design measures: 1) the process air fans are housed in a separate mid-mezzanine level within the reactor building; and 2) they are low horsepower centrifugal fans [16]. Promotional literature from American Bio Tech states that the finished compost is pathogen free upon discharge from the cure reactors, free from objectionable odour, and has a pH ranging between 6 and 8 [16].

Marketing

Markets considered most likely for the final compost product are the ornamental and horticultural industries, as well as various public agencies responsible for restoration of public lands [16].

3.2.3.2 American Recovery Corporation

American Recovery Corporation (ARC) is a joint venture between Potomac Capital Investment Corp. (a wholly-owned subsidiary of Potomac Electric Company of Washington, DC) and Sorain Cecchini Recovery, Inc. Sorain Cecchini is an American affiliate of Sorain Cecchini of Rome, Italy [17]. The technology developed by Sorain has been available for 25 years. The company has a number of operating plants overseas that include a MSW composting component. The front-end processing line is also being marketed as part of a combustion process (mass bum or RDF).

Description of Operation

In the processing line, trommel screens are used to segregate the organic fraction. The remainder of the waste stream then goes through a number of unit processes including size reduction and air classification. According to ARC, this results in the production of a number of recyclable feedstocks. The system includes equipment designed to remove polyethylene film from the waste stream. The film serves as feedstock for the production of waste bags. Hand sorting is used primarily for cardboard and aluminum [18].

ARC is in the process of building a pilot in-vessel composting facility in Santa Barbara, California. The system could be used by municipalities to conduct composting trials of their yard waste and organic residues [19].

ARC will initially concentrate on using the composting component of its system for source separated leaves and yard debris. It is expected that the amount of residuals after composting and recycling will be on the order of 25% by volume.

3.2.3.3 Ashbrook-Simon-Hartley

This Houston-based company sells a tunnel reactor in-vessel composting system. It has operational sludge composting facilities in Newburg, Oregon and in Hamilton, Ohio, as well as a mobile sludge unit in Oceanside, California. The company also has a facility under construction in Hickory, North Carolina and one in the design stage in Camden County, New Jersey. The company has two plants operating in Germany, both privately owned and with a processing capacity of 365 to 455 tonnes/day [20].

Description of Operation

The pre-processing line is designed to pull out paper, glass, metals, and plastics, but because the system does not have a screw or auger inside, it can handle inorganics. The material coming out of the reactor would be ground and screened. The company strongly encourages integrating recycling programs with the composting operation, and also emphasizes that the actual pre- and post-processing line should always be tailored to a community's needs [5]. The length of the composting process is 10 days in the vessel and several weeks of curing. The residuals after composting is about 20% [5].

3.2.3.4 Bedminster Bioconversion Corp.: The Eweson Process

Feedstocks

The Eweson digester processes a mixture of solid waste and sewage sludge in approximately the ratio that the population of a typical municipality produces them. The digester can process sewage sludge either in the raw or digested form, and at solids contents ranging from 4% to air-dried. In other words, the process can take sewage sludge at any stage in its treatment in a wastewater treatment plant [21].

Description of Operation

The company strongly encourages community recycling programs, but is capable of designing a system to sort out recyclables prior to composting [5]. Bedminster's processing line prior to composting includes hand-sorting and magnetic separation. Marketable inorganic materials such as ferrous metals, aluminum, PET and HDPE plastics are removed [21].

The Eweson Digester is divided into three compartments and rotated by means of an electrically driven bullgear. Air is circulated through it at controlled rates in a flow direction counter to the material flow.

Only large metal objects are removed before the refuse is dumped into the receiving hopper. The remaining waste is fed into the first compartment by means of a hydraulic ram. Sewage sludge is added to bring the moisture content up to about 50% and to bring the carbon-to-nitrogen ratio to 35:1 or less.

Internal projections in the digestor break up the rubbish bags and other large objects during the tumbling action, exposing more surface area to the bacterial action. The aim is to attain as high a temperature as possible in the first compartment to soften the incoming material. This is achieved by: 1) the bacterial action; and 2) the circulating air, high in moisture and carbon dioxide, that has already been heated in passing through the second and third stages. The carbonic acid from the carbon dioxide dissolves non-water-soluble microbial nutrients in the waste. Temperatures up to 71° are reached in Compartment 1.

After one to two days, 85% of the material in the first compartment is transferred to Compartment 2. The remaining 15% serves as an inoculum for the next batch. In Compartment 2, the waste continues to decompose at a high rate, with thermophilic bacterial action. This compartment is also initially charged with a special inoculum. After one to two days, the waste is transferred to Compartment 3, again leaving about 15% behind to serve as inoculum.

In Compartment 3, the bacterial activity is less intense and the incoming circulating air has the lowest moisture and carbon dioxide content. A certain amount of drying occurs. The retention time in Compartment 3 is also one to two days [21].

The size of the system ranges from 45 to 270 tonnes/day. Bedminster's target-markets for the system are municipal entities with populations of 10,000 to 100,000 [5].

Quality Control Parameters

In order to significantly reduce pathogens, the solid waste is maintained at minimum operating conditions of 40°C for five days. For four hours during this period, the temperature exceeds 55°C [20]. To further reduce pathogens, the solid waste is maintained at operating conditions above *55°C* within the vessel and in a dynamic aerated phase for a period of time long enough to comply with PFRP (Processes to Further Reduce Pathogens) requirements [21].

According to the vendor, the Bedminster's Eweson system has the ability to dilute concentrations of heavy metals which exist in sewage sludge. When liquid sludge is used (in contrast to dewatered sewage sludge), the solids in the sewage sludge are one-tenth or less the volume of the total volume of sewage sludge and solid waste processed. As a result of microbial activity in the digester, the solids in the sewage sludge, including the heavy metals contained in the mixture, are dispersed. This dispersion reduces the concentration of metals to approximately one-tenth of their input amounts [21].

In a municipal situation where toxic metals in sewage sludge are a potential problem, dewatered sewage sludge would not be used in the Eweson system. Rather, sewage sludge would be delivered to the Bedminster plant at a solids content between 5% and 10% [21].

Markets

Compost markets that the company is developing include horticulture, agriculture, silviculture, sod farms, and home garden use [5].

Environmental Impact

Potential negative environmental impacts are discussed by the vendor as follows:

Air:	The only air-born effluents are carbon dioxide and water vapour.
Water:	None.
Noise:	Low noise levels from electrical motors.
Odour:	No odours other than those emanating from the solid waste while it resides on the tipping floor. Sewage sludge is kept in closed tanks.
Visual/ Aesthetic:	Tipping and curing areas under roof; overall appearance of the plant similar to that of any modem manufacturing facility.
Other:	"Tailings" from the plant would be free of putrescible material and therefore incapable of creating leachate in a landfill.

3.2.3.5 Compost Systems Company

The Compost Systems Company (CSC) operates three different types of in-vessel composting systems. The company refers to them as Enclosed Dynamic Composting, or EDC, systems:

1. Paygro, a horizontal bin-type system
2. Dynatherm, a horizontal plug-flow reactor
3. Fairfield, a circular digester (sold by CSC for sludge only, with Fairfield marketing the system for MSW composting)

The following pages present information regarding Paygro and Dynatherm. Information regarding the Fairfield system is described under the heading of the Fairfield Service Company.

Pavgro

Dewatered sludge, finished compost, and small amounts of fresh bulking agent (e.g. bark, sawdust, tree trimmings, wood chips, etc.) are mixed in appropriate quantities to achieve a feed mixture of at least 40% dry solids. An automatic mixing system discharges the mixture onto the central conveyor for loading of the reactors [22].

Material moves via conveyors to either of two parallel reactors. The reactors are 6.1 m wide and can range in length from 61 to 305 m. Operating depth is normally 2.9 m, but can be increased up to 3.8 m for extremely large installations, or when land area is limited.

Composting material is normally retained in the reactor for a period of 14 days (longer for extremely cold climates), during which time it is remixed and repositioned at least two times. Remixing of the reactor contents assures that all material is exposed to sufficiently high temperatures to destroy pathogens; this remixing also improves porosity of the composting mix. Air is supplied to the reactors by a series of fans positioned along the reactor walls. The fans are designed to either force air upwards or downwards through the reactor contents. An automatic control system regulates both the quantity and direction of air from temperature sensing devices located in the reactors. Material is removed from the reactor and either relocated in the tanks or discharged as finished compost (55% to 70% dry solids) to storage prior to sale or recycling as the primary bullring agent [23].

In accordance with the U.S. EPA requirements for pathogen control, the compost mass meets or exceeds a temperature of 55°C for a minimum of three days. The control system can provide precise control of the air throughout the reactor contents to guarantee that the requirements are met. Mixing and turning the contents of the reactor further ensures that all finished compost has been exposed to proper temperatures. Laboratory analyses and temperature profiles have demonstrated the system's capability to meet EPA's requirements [24].

Dynatherm

Dewatered sludge (generally 15% to 35% dry solids) is mixed with small amounts of fresh amendment (e.g. bark, sawdust, wood chips, tree trimmings, etc.) and appropriate amounts of recycled compost to achieve a feed mixture of at least 40% dry solids. This mixture is then conveyed to the Dynatherm reactor where it is retained and aerated for a period of 14 days or more [24). The reactors are rectangular in shape and can be manufactured from steel or concrete depending upon size and location.

For a single module system, the material is remixed during the recycling step. For a dual or multiple module system, an intermediate mixer is provided to ensure optimum porosity of the material entering the next module. Upon completion of the aeration cycle, the compost is discharged from the final reactor and either recycled as a principal component of the mix or discharged as finished compost.

Air is supplied to each module by two low pressure fans, each providing air to a distinct zone within the module. An automatic control system regulates the amount of air to each zone through temperature feedback from the composting mass. Off-gas from the system is discharged through fans in the roof of each module. The off-gas can be vented, as required, to an odour control system designed for the specific facility.

Steel tractor modules can be factory assembled and shipped on a standard low-bed truck. Depending on the size of the installation, from one to ten modules can be combined either end-to-end or by stacking one on top of another. Separate control and discharge modules are connected to the reactor modules to complete the installation.

The heart of the Dynatherm system is a moving floor, which provides non-compacting and reliable transfer of the composting mass from the feed to the discharge end of each module. The floor consists of a number of parallel sliding members, or planks, separated only by narrow aeration headers. Every third plank is attached to a single hydraulic cylinder and moves independently from the other planks. Each third of the floor planks is retracted in sequence with the overbearing load being held in position by the greater friction of the stationary planks. After all the planks have been retracted, they move forward simultaneously in the direction of discharge, carrying the overbearing load with them. The sequence is then reinitiated to move the load in a step-wise fashion toward the discharge end [24].

3.2.3.6 Ebara Environmental Corp.

Ebara Environmental Corp., a Japanese company, has three operating MSW composting plants, two in Japan and one in New Zealand, as well as other projects in various stages of development [5].

Feedstocks

The composting feedstock consists of about 80% of the incoming waste stream, consists primarily of garbage, paper, wood and earthware. Ebara requires its clients to also have in place a hazardous waste collection program, and will not accept bulky refuse, e.g., carpet, bicycles, and such materials as gas cylinders and fluorescent lights at the composting facility. Sludge can be used as a moisture adjustment for the compostable materials of the MSW stream [5].

Description of Operation

Ebara has developed compost processing equipment called a Selective Pulverizing Classifier (SPC). The SPC consists of a rotary screen drum and scrapers that turn in response to the rotary drum. MSW is pulverized and classified by utilizing a difference in strength or fragility of material in the MSW. This machine has four steps of pretreatment: separation, pulverizing, screening, and moisture adjustment. A magnetic separator is used with the SPC on the front end of the system prior to composting.

Ebara's composting phase uses the Round-Trip Paddling Fermentor, a horizontal composting bin with a special paddle type rotator. The literature says the bin provides stirring, mixing, transfer and aeration of the composting mass. The company's post-processing equipment is known as its refining system. When needed, an Electro-Static Separator Compost Refiner is used. This is a sorting machine that utilizes the difference in electric conductivity to remove fine glass, plastics, etc. from the compost. When used together, says Ebara, the compost has a foreign matter content of less than 1% [5].

The level of residuals after composting that need to be landfilled is about 20%. The length of the composting process is 10 days in the vessel and 20 days in curing piles. The minimum size of the system is one ton/day; the maximum capacity is 900 tonnes/day.

3.2.3.7 Fairfield Service Company

Feedstocks

The Fairfield system is designed to handle a mix of municipal solid waste, commercial solid waste, and dewatered sewage sludge (dewatered to approximately 20% dry solids) [25]. The company's technology is currently in operation at the Delaware Reclamation Plant in New Castle, Delaware. The company does not own projects it builds, although it will operate them, as is the case in Delaware [5].

Because source separation is considered more effective than mechanical separation, Fairfield strongly encourages communities to implement recycling programs. Communities are also required to implement a hazardous waste collection program [5].

Operating Description

A conveyor carries waste materials to a picking area, where non-processible materials are removed manually. A hammermill shreds the remaining material into a coarse grind. The classifier removes metal and glass for salvage. Combustible material such as wood, plastics and rags are used as auxiliary fuel for product dryer. A pulper provides final grind and adds moisture to the organics (including paper) before digestion.

The homogenized mixture is conveyed (through an enclosed chute) into enclosed composting digestors. The Fairfield digestor is a circular vessel convened with a dome. Aerator augers are suspended from a bridge that travels around the top of the digester wall. Integral units of the bridge include: 1) drive machinery to rotate the bridge; 2) machinery for the multiple aerator augers; and 3) a conveyor which transports incoming material from an overhead center hopper to the place where it enters the digester near the wall. The material is aerated and moved toward the center discharge by the action of the multiple augers. A conveyor at the bottom of the digester removes digested material. Air is forced into the digester by a motor driven blower and distributed throughout the material by pipes [26].

A self-generated temperature of approximately 66°C is produced and maintained by the metabolism of the aerobic-thermophilic microorganisms. The speed of the augers, the rate of rotation of the carriage assembly and the amount of air introduced into the digester are controllable to obtain optimum temperature and correct retention time of material in the digester [26].

The retention time is 5 to 7 days. The composted product is fed into a hopper which discharges the material uniformly at variable rates. The drying system consists of a humus-burning incinerator, with an auxiliary oil-fired burner, providing heat to a horizontal rotary dryer. Air to dry the humus product is drawn by an induced draft fan through the dryer via a cyclone and venturi scrubber.

Compost discharged from the digesters can be further processed by drying, screening or pelletizing it into products for marketing such as bedding for poultry producers, and as an ingredient in lawn fertilizer and soil mixes [25].

The amount of residuals requiring landfill is 15%. The minimum size of the Fairfield system is 45 tonnes/day. There is no maximum capacity [5].

Quality Control Parameters

Efficient pathogen destruction is achieved by maintaining sufficiently high temperatures to ensure pasteurization [25]. The Fairfield digester meets the requirements of the U.S. EPA that the composting material be maintained within a vessel at operating conditions of 55°C or greater for not less than three days [27].

Marketing

The primary market that Fairfield is developing for the compost is in horticulture [5].

3.2.3.8 International Process Systems

Feedstocks

Existing IPS facilities in Connecticut have successfully composted a wide variety of wastes: mushroom farm waste, juice mill pomace and sludge, food processing waste, fermentation waste, agricultural waste, leaves and chipped brush, municipal sewage sludge [28]. Materials used as bulking agents include sawdust, recycled compost, shredded leaves, wood chips from waste brush or clean construction wood waste, and shredded paper [29].

Description of Operation

The entire operation takes place in a weatherproof building. Incoming waste is mixed with bulking agents and loaded into the space at the front of the bay. Days later the finished compost is removed at the other end of the bay.

A mixer/agitator machine works the compost every day, starting at the back end by removing the finished compost and moving towards the front, mixing, agitating, and moving the material 3.7 m down the bay every day, thus creating space for a new load of waste. Each bay can handle up to 10.7 m^3 waste per day [28].

Compost remains in the bays for a minimum of 18 days, assuming the compost is moved through the bays by operation of the agitator once a day, 7 days per week. The retention time can be increased or reduced. The actual solids retention in the composting system is also dependent on the degree to which compost is recycled as a bulking agent. IPS claims that, through the use of recycled compost, a product is obtained which eliminates the need for further curing [29].

Temperature and ventilation controls are used to maintain aerobic conditions and optimum temperatures during the composting process. A series of blowers are mounted at intervals along the sides of the outer bays. They are controlled by timers or by an automatic feedback system for forced aeration. The airflow is upward from the bottom of the bay via a system of perforated pipes. Each blower is independently controlled allowing precise temperature management during each stage of the process [29].

Dry, stable compost is discharged into a storage area at the end of the bays. The IPS system is modular; the basic module is a horizontal bay, 1.8 m wide by 1.8 m high and 67 m long. As many as four bays can be placed side by side and served by a single mixer/agitator. When greater capacity is needed, additional bays can be added without disturbing ongoing operations [28].

Key Characteristics for Biofilter

International Process Systems recommends the use of a biofilter for odour control. Several materials and soils can be used in the construction of biofilters. The quality of the medium is important in the performance of the filter.

The following are the key characteristics given by International Process Systems for biofilter media [29]:

pH	6-8
Moisture content (%)	10-40
Porosity (% air-filled)	30-60
Organic matter content (%)	5-30

3.2.3.9 OTVD

OTVD, a French company, markets an MSW processing system that includes a patented composting technology known as Siloda. The minimum size of the OTVD system is 45 tonnes/day; there is no maximum [5].

Feedstocks

The feedstock consists of municipal solid waste, sewage sludge, and a "relatively dry organic substrate" such as sawdust, wood chips, or ground bark. Dry amendment is needed to obtain a porous mixture with an acceptable degree of moisture and the proper C/N ratio [30].

Description of Operations

Pre-processing of the waste includes magnetic separation, air classification, shredding, and passage of the material through a rotating screen sized at 2.5 to 7.6 cm.

In the Siloda process, fermentation takes place in parallel silos installed in a roofed shed. The silos are open at both ends to admit a horizontal paddle wheel. The paddle wheel travels on rails on top of the walls separating the silos. The number of silos is variable and depends on the quantity and quality of the product to be treated each day.

The product is regularly turned over by the paddle wheel, the blades of which slice the compost from the bottom upwards and drop it into an Archimedean screw housed in the centre of the paddle wheel. This screw flings the product into an adjacent silo and in doing so aerates the product and equalizes fermentation. The wheel is transported from one silo to the next. The air required for composting is injected via piping installed in the bottom of the silos. [30]

The compost remains in the vessel for 10 to 15 days, gradually being moved throughout the system by the paddle wheel. The material is then cured for 60 days in a curing yard. After the composting phase, the material is screened to a size of 0.6 to 1.9 cm. The back end of the system also includes pulverization and air classification. About 50% to 70% of the incoming waste stream is composted [30].

Marketing

Marketing is done by another subsidiary of OTVD's parent company [5]. Primary markets for the end product have been mushroom growers, vineyards, farms, greenhouses, and landscapers.

3.2.3.10 PURAC In-Vessel Composting Systems

The in-vessel composting system which PURAC offers today is the fourth generation in its line of composting technologies.

Feedstocks

Feed to the system is partially dewatered sludge (18% to 35% solids from a belt press, vacuum filter, centrifuge or other similar device). Dewatered sludge is mixed with recycled compost and a carbonaceous additive to provide proper porosity, moisture content, and C/N.

Description of Operation

Generation 3 consisted of a closed, cylindrical vertical composting tank with a new air exhaust system The purpose of the change was to locate the exhaust air nozzles on the vertical pipes approximately 1 m down in the material. In doing so, the process air is exhausted at the wannest level where the air has the maximum content of moisture. This condition provides for a more efficient withdrawal of water. Air flow as well as the necessary amount of carbonaceous material used are reduced. Another advantage with the Generation 3 concept is that the exhaust air flow is larger than the amount of air supplied at the bottom. The difference is made up by fresh air drawn from the top through the layer of new material. This material has a very high oxygen demand, which can be satisfied through this additional airflow from the top. The process is designed to start quicker, which saves time or reactor volume [32].

In addition to employing this improved air exhaust system, PURAC's new Generation 4 system utilizes a rectangular rather than a cylindrical vessel. PURAC maintains that its new rectangular vessel eliminates many of the problems associated with cylindrical. The mixing screw for a cylindrical vessel must be located in the centre of the vessel, where it is affected by corrosion and wear 24 hours a day and is impossible to inspect, maintain or replace without emptying the reactor. The process of emptying the cylindrical reactor, inspecting or replacing the screw, and recharging and re-establishing the biological process takes six to eight weeks. Since inspections should take place every year, PURAC determined that this was not acceptable [33].

The Generation 4 rectangular reactor circumvents such problems through the use of a travelling parascrew. Only the screw comes in contact with the material, and only at the time when it passes through the material, a period limited to 40 hours per week. In the Generation 4 reactor, "the driving unit and gears are located outside the reactor and can easily be inspected and maintained even during operation. When the screw is not in operation it is outside the corrosive compost in the reactor and stored in the ventilated 'garage' at the end of the reactor. Thus the corrosion is minimized." [32].

Other advantages to the rectangular reactor and travelling screw which PURAC cites include: I) expandability of the rectangular reactor, 2) avoidance of anaerobic zones; 3) flexibility in sizing the reactor; and 4) improved material loading and distribution [32].

PURAC offers this further description of the Generation 4 system: "The rectangular vessel is built up by modules having a length of approximately five meters. Between these modules there are partition walls. These are limited in height and enable the infeed as well as outfeed device to pass above and below. The vessel can be built to virtually any size. To increase the size, the length of the vessel is extended with additional standardized modules. The same standardized infeed and outfeed devices are used. This means that a rectangular reactor is divided into a number of separate compartments. These can literally be operated separately but are served by the same infeed and outfeed devices. The internal walls make it possible to empty sections of the vessel." [33].

Following processing, the compost can be cured either within the original reactor vessel, in a separate curing reactor, or on an aerated outdoor or indoor surface. If an open curing method is used, the curing floor area is covered by a layer of special porous asphalt over a layer of sand where perforated air supply pipes of plastic are situated. The air passes from the pipes through the sand and asphalt layers [32].

3.2.3.11 Recomp, Inc.

Recomp is licensed by Bedminster Bioconversion to market the Eweson digester in some western states. The company also is one of the few vendors with an operating MSW composting facility, a 50 ton/day co-composting project in St. Cloud, Minnesota. The facility began operating under Recomp's ownership in April 1988.

Feedstocks

The substrate to the co-composting operations is about 65% MSW and 25% sludge, with a solids content of about 5%. The MSW feedstock consists primarily of food waste, paper, glass, yard waste and some plastic, non-ferrous metal, and textiles [5].

Description of Operation

The incoming waste stream goes through a pre-sorting process on the tipping floor, then goes though a bag splitter and into a trommel screen that separates the light and heavy fraction. The recyclable materials are removed manually by hand sorting. The remaining material (except for ferrous that is extracted by magnetic separation) is mixed with sludge and is loaded into the digester. According to Recomp, the MSW is not shredded prior to composting. The rotating action of the digester as well as a device inside accelerates breakdown of materials.

The material remains in the digester for four to five days, and then is transferred to curing piles for 14 to 21 days. About 65% of the incoming waste stream actually enters the composting system. The material passes through a 3.8 cm. trommel screen when it exits the digester. The screen removes most of the plastic, aluminum, and bi-metal cans that are not removed manually. After the material is cured, it is passed through a 1.9 cm. screen. A 1 cm. screen is available if a finer product is needed. The quantity of residuals that need to be landfilled after composting is 30%.

The minimum size of the system is 45 tonnes/day; the maximum capacity is 365 tonnes/day [5].

Marketing

"In addition to Christmas tree farms, Recomp plans to sell the product for use in public works/highway applications, forest nurseries, and planter mix manufacturing. The current price for the compost is \$2.31/m^3 unscreened, and \$7.69/m^3 screened [5].

3.2.3.12 Royer Industries, Inc.

Royer's involvement in the composting industry previously *was* primarily as a supplier of screens and shredders to sewage sludge and leaf composting facilities. Recently, however, the company expanded its line to include the Enclosed Dynamic Composting System it had developed for processing sludge, MSW, and other organic wastes Royer will be supplying its system to the co-composting facility under design in Brooksville, Florida. The equipment will *be* used for the compost curing phase [5].

Feedstocks

Feedstocks to the Royer Industries composting systems are dewatered sludge, MSW, other organic wastes, and bulking agent (sawdust) [5,34].

Description of Operation

Composting is conducted in parallel 2.4 m wide troughs. Starting at the unloading end of the first trough, the compost turner moves through the trough contents, mixing, breaking up, and turning the material and moving it forward about 3 m. Each operating day, dewatered sludge and bulking agent are placed in the loading end. When the turner reaches the loading end, the new material is thoroughly mixed and moved into the aeration zone. After the turner completes its cycle in one trough, it moves onto the automatic transfer dolly, which positions it at the next trough to repeat the cycle. The Royer compost turner will mix four troughs of composting material in an 8-hr day. The turning and transfer cycles are totally automatic, so the operator is free to load and unload material and to perform routine maintenance.

The length of the troughs will depend upon the planned work schedule and the required composting period. The system can be designed to operate on a 5, 6, or 7-day per week schedule. At least 14 days are required to produce a compost product, which should then be cured in a separate pile. If the composting process is extended to 21 days, the curing period can be eliminated. Assuming a 5-day work week, the material will be turned 10 times in 14 days, requiring troughs 33.5 m long [34].

During the composting process, positive aeration is achieved by a series of blowers, which force air into the mixture through a network of perforated pipe. An automatic control system, operated by temperature probes and timers, rums the blowers on and off to maintain proper composting temperatures. Chart recorders plot the temperature measured by sensors built into the walls of the troughs [34].

Surge loads can be processed by making a second pass in a day, or by adding a non-scheduled work day. Composting time can be extended without the addition of new material. To compensate for variations in moisture content, operators can adjust the quantity of bulking agent added to the mix. The system's total capacity can be increased by adding troughs [34].

3.2.3.13 Taulman Composting Systems

Feedstocks

Feed to the system is partially dewatered sludge (18% to 35% solids) from a belt press, vacuum filter, centrifuge or other similar device. Dewatered sludge is mixed with recycled compost and a carbonaceous additive to provide proper bed porosity, moisture content, and C/N. Sawdust, bark chips, shredded newsprint, rice hulls, peanut hulls, milled straw, bagasse, ground leaves, other yard waste, and corncobs have all been used successfully as carbonaceous additives in the systems [35].

Description of Operations

The compost system consists of a completely enclosed, mechanical composting reactor and a separate enclosed product curing reactor. The enclosed reactors make it possible to control composting temperature and aerobic conditions within a close tolerance, thereby ensuring a stable final product. The system is designed to completely eliminate odour [35].

The feed is introduced into the top of the vessel and composted for a period of approximately 14 days in the enclosed bio-reactor in a plug-flow, continuous regime. Air is fed continuously into the bottom of each reactor, with positive control maintained by removing air uniformly from the top of the reactor. Proper composting temperatures are maintained in the bio-reactor to effect pathogen kill and organic solids stabilization.

Temperature of the composting sludge, and the carbon dioxide or oxygen content of the off-gas stream are monitored continuously and sent to a microprocessor to control the quantity of air fed to the bio-reactor. Integration of these control functions allows complete control over the composting conditions.

A temperature profile through the vessel shows higher temperatures near the top, and somewhat lower temperatures in the centre and bottom. This temperature variance, together with differences in oxygen content from top to bottom, results in different zones of microorganisms being established throughout the height of the vessel. Each zone has a specific function, such as virus inactivation, weed-seed destruction, pathogenic organism kill, and organic material conversion to humus. Since this is a plug-flow reactor, all sludge must travel through each of the zones. The compost is not mixed so that the different zones are kept intact.

The composted material from the bio-reactor is transferred into the top of a 20-day cure reactor where stabilization of the organic material is completed. Air is fed into the cure reactor to assure aerobic conditions and to remove moisture via evaporative cooling.

The normal daily operating sequence begins with the bio-reactor outfeed device discharging approximately 1/14 of the contents of the bio-reactor into the conveyors leading to the top of the cure reactor. The cure reactor outfeed device is simultaneously started and final compost product discharged. This operation requires about 2 hours.

Dewatered sludge cake, recycled compost, and carbonaceous material are combined and transported to the top of the bio-reactor where mixing takes place. The mixed material is then charged into the top of the bio-reactor. This operation also requires about 2 hours.

The final product from the cure reactor is a pathogen free humus-like compost product suitable for use as a high quality soil conditioner. Taulman reports the following characteristics as typical of the final product [35]:

Moisture, %	50-60
Nitrogen. %	1.0-1.7
Phosphorous, %P_2O_5	0.8-3.3
Potassium, %	0.1-0.4
Bulk density, kg/m^3	300-500
Volume reduction, %	25-35
Water absorption capacity, %	40-70
Humic acid content, % (based on total organic solids)	2.0-5.0
Pathogen destruction	Complete

Economics

According to Taulman, the total present worth cost (capital and operating) of the Taulman system is about the same as that of a well designed windrow or static pile facility. If a cover is required for the windrow or static pile, the Taulman system should be less costly. It will be less costly than incineration and heat drying.

The power requirement is low for the Taulman system. The only continuously operating machinery are the blowers which supply air to the reactors. One man for one-half shift is generally required to charge one bio-reactor and one cure reactor daily. The system requires no operator attention during the other two shifts each day.

3.2.4 Hybrid

3.2.4.1 California Co-Composting Systems

Founded in 1982, CCSI is the licensee in 13 western states for the Voest-Alpine composting equipment from Linz, Austria. Voest Alpine has 12 plants operating in Europe. CCSI facilities range in size from 725 to 900 tonnes/day [5].

Feedstocks

Sewage sludge and MSW are fed to the system at a ratio of 1 to 4 [5]. The client is required to implement a hazardous waste collection from households and businesses.

Description of Operation

The Voest-Alpine composting system includes a rotating drum and aerated windrows. The processing line prior to composting consists of hand sorting, magnetic separation, air classification, shredding, and screening to 8 mm. The post-processing line includes screening to a particle size of 8 nun, air classification, and magnetic separation.

Material is composted in the vessel for 28 days, followed by four to six months of curing in windrows. Between 60% and 80% of the incoming waste is actually composted. The amount of residuals will vary from 8% to 23%, depending upon the end product market [5].

3.2.4.2 Harbert/Triga

Harbert/Triga has an operational sewage sludge composting plant in Saint Palais, France. The company also builds and operates plants which process both MSW and sewage sludge.

MSW/Sludge Co-Composting

Most of the waste processing is done at the front end of the system and includes: hand-sorting, magnetic separation, air classification, shredding, grinding, and use of a vibrating screen. Most of the compostable materials are separated out in one step; further processing is used to recover recyclables. After composting, the material passes through a magnetic separator and is screened. The compost remains in the fermentation tower for seven days, and then is cured in windrows. The length of the curing time depends on the end use. Between 20% and 25% of the incoming waste stream is composted. Feedstocks include yard waste, food waste, and sewage sludge if designed into the process. The amount of residuals that need to be landfilled after composting ranges from 45% to 80%, depending on the end use. The facility size ranges from 9 to 554 tonnes/day. Markets for the final compost include vineyards, fruit tree growers, plant nurseries, and soil amendment for public works projects [5].

Sludge Composting

The following information is based upon Harbert/Triga's sewage composting plant in Saint Palais, France.

Wet sludge is mixed with a bulking material (usually a combination of sawdust and pulverized pine bark). Mixing is monitored to produce an appropriate mixture with a water content of 65% [36].

The mixture of sludge and sawdust is poured into one of the four 65 cells of the two fermentation towers. A non-stop air flow rate is sucked through the mixture, the temperature of which rises rapidly to over 70°C. Air is finally scrubbed in a lime solution before being released into the atmosphere.

In completely filled cells, one third of the content is taken out every day to be poured back on top of the cell. After 10 to 12 days, the fresh compost is removed to be piled onto the covered curing yard. Curing compost piles are turned with a front loader every two weeks in order to maintain an appropriate oxygen content and temperature.

After two months, the compost is ready to be sold. Material from Harbert/Triga state that the compost has the following characteristics and nutrient contents [36]:

Water content	45 to 50%
Organic material (related to dried material)	85%
Nitrogen	2.0%
Phosphorous	1.5%
Potassium	0.2%

Elements such as barium, copper, zinc, etc. can also be found.

It has been observed that total losses of the incoming mixture (sludge plus sawdust) are within the 40% range [36].

3.2.4.3 Waste Processing Corporation — the DANO System

Over 200 plants worldwide utilize the DANO composting system [37]. Existing DANO composting plants range in size from 45 to 900 tonnes/day [5,38]. In addition to Waste Processing Corporation, Riedel Waste Disposal Systems, Inc. also is licensed to market the DANO composting technology.

Feedstocks

DANO plants process municipal solid waste. The compostable fraction of MSW (primarily newspaper, corrugated, mixed waste paper, yard and food wastes) is the feedstock to the composting system. Sludge can be added to the MSW prior to being loaded in the drum [5,38].

Description of Operation

MSW is tipped onto a concrete floor or pit in an enclosed receiving station. Recyclable items are removed and placed in bins for transport. MSW is then placed in a large, slowly rotating drum. This drum is about 3.6 m in diameter and 24.5 m in length. The drum rotates at 1 to 3 rpm. The drum is designed to quickly pulverize and homogenize the waste material. Air and water are added to the waste to hasten the process. After 4 to 12 hours in the drum, the waste is removed and screened to sort out the oversized items. Alternatively, such items may be screened out earlier, on the tipping room floor. A double screen located inside the drum may be used to separate the refuse into three separate fractions. Coarse and medium fractions are then available for magnetic and hand separation of recyclables.

Waste material is carried by conveyor from the drum to cither windrows or aerated static piles. Active composting for both methods is about 21 days, with approximately 6 weeks for curing.

The amount of residual material to be landfilled after composting is 20% by volume, or 30% by weight, and varies according to end use.

3.3 Canadian Technology

A small number of Ontario municipalities have been approached by the larger U.S. and European solid waste processing equipment manufacturers with offers to install large, turnkey recycling and composting facilities owned and operated by and for the benefit of the equipment vendor. This recent manifestation of interest in the Ontario market stems from two important public announcements. The first concerns a new government policy objective to divert from landfill 50 percent of the municipal solid waste stream by the year 2000. The second concerns the Greater Toronto Area (GTA) Regional Governments' decision to work together to resolve their waste disposal crisis. Later in 1989, they intend to issue a request for proposal (RFP) for the disposal of all of the GTA municipal solid waste estimated to exceed 3 million tonnes annually. The sheer volume of waste to be diverted and available for recycling and composting has captured the attention of the many vendors and entrepreneurs.

In Ontario, the legislation requires that major projects of this type must undergo rigorous environmental assessment and scrutiny by the public and the regulators. To avoid this costly and time consuming process, new recycling and composting planning in Ontario to date has resulted in designs that limit the plant waste production capacity to less than 200 tonnes/day. Approval of these facilities under provision of the Environmental Protection Act are less tedious and less costly since extended public hearings are avoided. The relatively small daily capacity of current projects has also allowed consulting engineering firms in Ontario with expertise in recycling and composting to dominate the Ontario scene. With the exception of existing static pile composting operations, all new Ontario facilities on the drawing boards appear to fit in the hybrid design category.

3.3 1 Channel System

The advantage claimed in Canada for the channel system is that a high rate of primary composting can be achieved in the channels thereby greatly reducing the time to complete the process and reducing the land area required for the facility. The channel system is non-proprietary.

The channel walls are normally constructed side-by-side and are 4 m wide, about 40 m long and 2 m high. A compost mixing device travels along the top of the channels to mix the compost and propel it along the channel towards the discharge end. (See Royer Industries Inc. who use a similar system.)

The blended raw materials are introduced at the loading end of the channel. During the retention time, usually ten days, several important activities take place. Aeration of the compost is provided through the diffusion bed which consists of a network of perforated pipes underlying a uniform thickness of crushed stone. While the oxidation of organic matter is a continuing process, the introduction of air is programmed to satisfy the biomass demand for oxygen and cooling.

The mixing device operates once daily along each channel to provide several important functions. The flailing teeth of the mixer breaks up colonized microorganisms and fungi and uniformly distributes them through the mixed biomass to further encourage rapid decomposition. The flail also mechanically breaks up the particles in the biomass to provide greater surface area and promotes contact with the organisms present. The mixing action releases water vapour and gases generated in the biomass while fresh air is introduced to provide cooling and aeration. The mixer transports the biomass toward the unloading end of the composting channel. With each daily pass of the mixing machine, the entire contents of each composting channel is displaced by about 3 m in the opposite direction away from the direction of the moving mixing machine.

3.4 Economics of Composting

The waste management literature contains descriptions of dozens of operating composting facilities. However, little information is available concerning the economics of building and operating those facilities. Tables 3-1, 3-2, and 3-3 present a summary of capital and operations and maintenance (O&M) costs reported for operating sludge, yard waste, and MSW composting facilities, respectively. The reported O&M costs for sludge composting facilities ranges from $40 to $537 per dry tonne, with the highest unit operating costs reported for the smallest facilities.

For yard waste composting, much less economic information has been reported. Reported O&M costs range from approximately $5.2 to $65 per tonne of yard waste. Tipping fees reported for MSW composting facilities, both operational and proposed, range from about $26 to $91 per tonne of MSW.

The reported capital and O&M costs vary over a considerable range due to several factors such as facility size and technology employed. Since the costs were not reported on a constant dollar basis, general price inflation also has an influence on the range.

But, other factors make an economic comparison of operating facilities and composting technologies very difficult. For example, local factors such as climate, labour, and equipment are highly variable. Moreover, accounting practices vary since composting projects are frequently public sector operations added to existing wastewater or solid waste operations. Cost items such as land, labour, and equipment needed for composting operations may be shared with other existing operations such that the costs attributed to composting reflect estimated incremental costs rather than actual market values. For instance, some of the capital costs for sludge composting systems on Table 3-1 include equipment for sludge dewatering. Others do not. Some, but not all, include the cost of land. To complicate matters, the definition of operations and maintenance costs are not precisely consistent. In summary, since the accounting rules used to allocate the costs (and revenues) of public sector composting systems are in many cases arbitrary, the reported results are not always comparable.

A more comparable way to describe the economics of composting is to develop and apply a consistent set of assumptions to a hypothetical or proposed situation, and project the costs of various technical or project size alternatives. A few examples of this approach to economic analyses appear in the literature. The East Bay Municipal Utility District [22] projected, for example, that alternative expansions to its existing pilot-scale sludge composting program would have annual costs of $129 to $172 per dry tonne of sludge with certain assumptions for the landfilling of reject materials and compost revenues. The five alternatives include several combinations of technologies.

Similar studies have been performed to project the costs and benefits (avoided disposal and product sales revenue) of various MSW composting and co-composting technologies and project sizes for specific municipalities [23]. It is important to recognize, however, that the utility of these studies is limited to the locale in which the governing assumptions apply.

TABLE 3-1. Summary of Reported Costs for Sewage Sludge Composting Facilities.

Facility	Size (tonne/day dry)	Capital Cost ($)*	O & M Cost ($/dry tonne)*	Reference
Swampscott, MA	0.3	52,000	548	20
Old Town, ME	0.3	325,000	527	20
Durham, NH	0.9	775,000	101	20
Clayton, GA	1.3	NA	376	8
Bangor, ME	1.9	17,800	40	20
Morgantown, NC	2.9	127,500	98	20
Occoquan, VA	3.3	1,750,000	59	20
S. Portland, ME	3.5	2,934,000	204	20
Sarasota, FL	3.9	NA	493	8
Middleton, NE	4.1	5,000,000	219	20
W. Warwick, RI	4.5	NA	49	20
Merrimack, NH	7.3	216,400	132	20
Hampton Roads, VA	9.0	3,000,000	242	15
Cape May, NJ	10.0	NA	279	8
Sussex Co, NJ	11.0	3,530,000	NA	6
Windsor, Canada	22.0	940,000	71	20
Camdon, NJ	22.0	1,880,000	169	19
Akron, OH	23.0	NA	175	8
Portland, OR	24.0	NA	149	8
Plattsburgh, NY	25.0	NA	129	8
Columbus, OH	36.0	7,776,000	194	15
Blue Plains, DC	62.0	5,820,000	225	20
Montgomery Co, MD	80.0	20,715,000	276	15
Philadelphia, PA	118.0	1,760,000	249	20

NA - not available

* All costs have been converted to Canadian dollars.

TABLE 3-2. Summary of Reported Costs for Yard Waste Composting Facilities.

Facility	Size (tonne/yr)	Capital Cost ($)*	O & M Cost ($/tonne of yard waste)*	Total Compost Cost ($/tonne)*	Reference
Westfield, NJ	14	NA	$11.5/m^3$ (64.83)[1]	$37.36/m^3$ (52.5)[2]	14
Woodbury, MN	105	NA	19.41	75.3	14
East Tawas, MI	125	NA	< 13	25.9	14
Omaha, NB	455	NA	4.7	57.6	14
Seattle, WA	3,266	NA	29.2	45.9	14
Morris Co., NY	6,800	774,000	45.1	NA	12
Montgomery, Co., MD	4,000	NA	23.9	131.8	14
Monterey, NJ	NA	NA	8.8	NA	1
San Mateo Co., CA	37,000	NA	$5.74/m^3$ (32.24)[1]	$8.68/m^3$ (25.2)[2]	21

Notes:

1. Assuming a yard waste density of 178 kg/m^3.

2. Assuming a compost density of 713 kg/m^3.

NA = not available.

* All costs have been converted to Canadian dollars.

TABLE 3-3. Summary of Reported Costs for MSW Composting Facilities.

Facility	Size (tonne/yr)	Capital Cost ($)*	O & M Cost ($)*	Tipping Fee ($/tonne)*	Reference
Fillmore Co., MN	16-22	1,310,000	NA	44-50	3
Swift County, MN**	22	1,400,000	266,000	76	13
St. Cloud, MN	14,000	NA	NA	50	21
Cairo, Egypt	44,000	770,000	NA	22	16
Portland, OR	200,000	13,100,000	5,000,000	44	4
Dade County, FL**	275,000	25,000,000	NA	26	11
Portage, WI	NA	NA	NA	39	21

NA = not available

* All costs have been converted to Canadian dollars.

** Proposed

With regard to MSW and yard waste composting, there does not appear to be any reported information indicating significant economy-of-scale in the sizing of facilities for the production of these materials. The O&M costs reported for sludge composting do, however, seem to indicate some economy-of-scale for that material. Regarding the reported economics of operating existing facilities, several of the referenced reports do mention that production costs increase markedly when facilities are used at less-than-capacity.

3.5 Marketing

Marketing plays an important role in the ultimate effectiveness of any program to compost wastes, whether the wastes be MSW, sewage sludge, yard debris, or another organic material.

The primary objective of securing a market is that of finding an end-use for the finished product. The compost process itself results in a significant amount of volume reduction. Consequently, if the finished product were simply disposed of, a certain amount of landfill space would nevertheless be conserved. In fact, there are those that believe that volume reduction is reason enough to implement a compost program [1]. However, the value of any program to compost wastes is greatly increased when an end-use for the product is secured the quantities of waste requiring landfill are reduced further, and a beneficial use for the product is found [2].

A secondary objective, and one that is not always realized, is to provide revenue from the sale of the compost. Twenty-five years ago, the driving force behind composting was the hope of selling the finished product at a profit. The difficulties today in siting and developing landfills, combined with an interest in conserving resources, has reduced the profit motive in composting to one of secondary importance [3]. Nevertheless, any revenues obtained from selling the compost product would, obviously, serve to offset the cost of processing.

3.5.1 Characteristics and Uses

3.5.1.1 Characteristics

The utility of compost as a soil amendment has long been recognized. The most beneficial characteristic of compost is its high organic content. Compost also contains certain nutrients that can be helpful in plant production. Selected characteristics of various types of composts are presented in Table 3-4. These characteristics include: moisture content, organic matter, C/N ratio, pH, nitrogen, phosphorus, and potassium.

TABLE 3-4. Characteristics of Various Composts.

	Moisture Content (%)	Organics (% dry wt.)	C/N	pH	Nitrogen (% dry wt)	Phosphorus (% dry wt)	Potassium (% dry wt)
BARK							
Japan [4]					0.800	1.70	0.500
MANURE							
Japan [4]					1.700	3.20	1.900
MSW							
France [5]	36-40	30-33	10-19	7.50-7.70			
France [6]	33-40	45-53		7.50-8.00	1.0-1.2		
France [7]	40-42	30-35	19-20	7.50			
France [8]					1.100	0.60	0.600
Italy [9]		41.39	24.50		0.960	0.68	1.010
Japan [4]					2.100	2.00	1.400
Oman [10]	35.90	55.00	19.00	6.63	1.300	0.40	0.600
Spain [11]		43.96	31.98	7.02	0.860	0.74	0.510
Spain [11]		69.43	24.15	7.16	1.330	0.83	0.950
Spain [11]		58.20	18.80	7.10	1.660	1.06	0.780
U.S.(Minnesota) [2]	46.90			6.80	1.080	0.35	0.760
MSN/PIG MANURES							
Italy [9]		25.01	16.60		0.830	0.55	0.560
PAPERS							
U.S.(New York)[12)				8.10	1.730	0.94	1.250
SLUDGE							
Japan [4]					2.300	4.00	0.400
U.S.(Oregon) [2]	58.96			4.74	1.810	1.79	24.050
SLUDGE/BARK							
Italy [13]	55.00	50.00	12.50	6.90	2.200	0.45	0.400
SLUDGE/VINEYARD WASTE							
Italy [13]	55.00	48.00	12.20	6.50	2.000	0.69	1.400
SPENT MUSHROOM							
Netherlands [14]	60.90	20.30			0.700	0.78	0.960
YARD DEBRIS							
U.S.(Minnesota) [5]				7.60	0.075	0.02	0.027
U.S.(Oregon) [2]	48.90	64.50		6.70	0.630	0.14	0.620
U.S.(Oregon) [2]	48.50	67.30		7.10	0.900	0.16	0.720

Because of the organic matter in compost, it can positively affect soil in a number of ways [2,4,16-21]:

Physical properties of soil	improves soil texture increases water retention capacity improves aeration capacity improves structural stability resistance to wind and water erosion stabilizes soil temperatures
Chemical properties of soil	increases nutrient content turns mineral substances in soil into forms available to plants regulates mineral input, particularly nitrogenous compounds serves as buffer in making minerals available to plants source of micronutrients
Biological properties of soil	affects the development of fauna and microflora renders plants less vulnerable to attack by parasites promotes faster root development of plants
Crop yields	can produce higher yields inhibits weed growth

3.5.1.2 Uses

A professional marketing firm has identified 22 major end uses for compost [22]. In addition to its beneficial properties as a soil conditioner, compost can be used as a mulch (to aid water retention and inhibit weed growth), as a top dressing (to improve appearance and inhibit weed growth), and for landfill cover [23].

Due to the beneficial characteristics of compost, the product can be used by a variety of market segments. The types of markets for a particular compost product are highly dependent upon the type of feedstock, quality of the product, and needs of the area. For example, in densely-populated areas, agriculture may not be a feasible market. The following are potential markets for compost products [2]:

- agriculture
- bare roots nurseries
- Christmas tree farms
- forest seedling nursery, reforestation
- golf courses, cemeteries, amusement parks, athletic fields, etc. for grounds maintenance
- highway construction and maintenance
- hydromulching
- land reclamation (landfills, quarries, strip mines, tailings areas)
- landfill cover
- industrial and commercial property landscaping
- parks and recreation areas

- public agencies
- residential landscaping and gardening
- sod farming

Agriculture

In connection with its use in agriculture, both the organic matter and the nutrient content of compost are of importance [24]. The fertility of the soil is a valuable environmental asset. In order to safeguard this fertility, the soil must be supplied with sufficient organic matter. According to Geilinger [25], compost is the best source of organic matter for this purpose.

A number of tests have been conducted on the effect of compost application on crop yields. Tests have shown that, when the compost has been properly processed and applied, high yields have resulted [3.5,20,26]. For example, application of MSW compost to vineyards in France has resulted in increased yields of 13% to 14% [5].

As part of an MSW compost project in Tennessee, MSW compost was applied to fields annually from 1968 to 1972. Field corn was grown annually from 1969 through 1983 using conventional soil tillage techniques. Corn grain yields were measured each year. Data collected over a 19-year period demonstrated that the beneficial effects of MSW compost application include sustained higher crop yields, a more favourable soil pH, increased organic matter and cation exchange capacity, and enhanced supplies of primary and secondary plant nutrients [3].

Research tests have also demonstrated that use of compost in conjunction with chemical fertilizers can be beneficial. In tests on corn production in Minnesota, fields treated with both compost and fertilizer achieved yields 17% higher than fields spread with commercial fertilizer alone [26]. Compost can increase efficiency in chemical fertilizer utilization [2,27].

Difficulties in exploiting the agriculture market include: 1) high costs associated with transport of compost products; and 2) difficulties in applying compost to the fields.

Nurseries

Compost can be utilized in a wide variety of nursery applications. Examples are bare roots nurseries, Christmas tree farms, container production, forest seedling nurseries. Results of a marketing survey conducted in the metropolitan area of Portland, Oregon, indicated that about 60% of nurseries surveyed used bark or bark dust products in their business, either as a soil amendment or in potting mixes. Next in terms of volume of use were sawdust, manures, and peat moss [2].

Tests in which compost served as a potting soil amendment have shown increases in growth that ranged from 0% to 50%. The use of compost in potting soils is attended by a slow release nitrogen, phosphorus, potassium, calcium, and other essential nutrients. It also increases porosity and aeration for healthier root development [28].

Landscapers

Significant quantities of organic soil amendments are used by landscapers, gardeners, and sod producers. Bark or bark dust is often used as a top dressing, topsoil primarily as fill for new plantings, and compost as a soil amendment [2]. New construction projects (e.g., residential housing developments and commercial buildings) create a high demand for the products.

Research by the U.S. Department of Agriculture and at Rutgers University has demonstrated that on soils with poor physical properties, compost used correctly will lead to the production of a better turfgrass than is true with the use of mineral fertilizers alone. Compost on turfgrass, leads to the slow release of nitrogen, and also imparts the resilience needed to absorb normal traffic wear and reduce compaction which can damage roots [29].

Public Agencies

Municipalities and other government agencies often require organic soil amendments for use as a soil conditioner or top dressing. Examples of uses are: parks, recreation areas, landscaping, turf repair, landfill cover, land reclamation, and highway construction and maintenance [2,21,30,31].

Residential Gardening

Large quantities of compost can potentially be utilized by the residential sector. The amounts are highly dependent upon the population density of an area and the type of housing, i.e., residents of single-family dwellings typically use greater quantities of soil amendment products than residents of multi-family dwellings.

Compost is generally used by the residential sector for the following purposes:

- as a soil amendment by improving the organic and nutrient content of the soil and increasing the soil's moisture holding capacity;
- as a mulch to aid water retention, inhibit weed growth, and add to the organic matter of the soil; and
- as a top dressing by improving appearance, inhibiting weed growth, and adding to the organic matter of the soil.

3.5.1.3 Competitive Products

In order for compost to have external markets, either markets must be expanded or compost substituted for another product [32]. Examples of materials that can compete with MSW compost for the soil amendment market include: bark and bark dust, manure, peatmoss, sawdust and shavings, straw, woodchips, topsoil, worm castings, and fish meal [2,33,34]. The kinds of products that would compete with compost are highly dependent on the geographic location, in particular the type of industry and population density.

3.5.1.4 Existing Markets

Efforts to market the finished compost products are meeting with a great deal of success in some locations and with some types of composts. The Middle East is an example of an area in which the demand for compost is great. With one exception, all of the facilities have existing markets capable of absorbing more compost than can be produced. In fact, many have one to two-year waiting lists for the product. Compost, with its high water retention capabilities, is ideal for desert countries where the agriculture is heavily dependent on irrigation [19].

A listing of markets (actual, targeted, or planned) for a number of composting operations world-wide is provided in Table 3-5. As can be seen from the table, a wide range of markets for the composts is being exploited.

3.5.2 Marketability

3.5.2.1 Product Quality

For a product to be marketable, it must meet the requirements of the user. Compost is no exception. The following criteria have been found to be of particular importance to potential compost users: quality; availability (convenience, steady supply, etc.); and cost [2].

Characteristics of High Grade of Compost

Product quality is generally considered to be the most important of the factors that affect the marketability of compost. Regardless of the type of compost operation, quality of the product is a function of the physical, chemical, and biological characteristics of the product. Examples of desirable characteristics are as follows:

Physical:	dark colour uniform particle size pleasant earthy odour absence of contaminants absence of clumps no visually identifiable contaminants (e.g., glass shards and pieces of metal and plastics) moisture content <50% (for ease of transport)
Chemical:	available nutrients (NPK) minimal levels of heavy metals, PCBs, PCPs, and pesticides/herbicides low salinity concentration
Biological:	sufficiently mature high concentration of organic matter absence of pathogenic organisms absence of weed/crop seeds

The characteristics listed above are of importance because they render the product attractive to users, and guarantee that it is safe to use [10]. As may be concluded from the information in Table 3-6, the quality requirements for a compost sold on the market may need to be adjusted depending upon the particular needs of the user [1]. An example of how a grading system can be utilized for different qualities of compost, and how those grades of compost are suited for particular applications, is given in Table 3-7.

Problems with compost quality vary with the type of feedstock. Table 3-8 presents the findings of a study conducted in Portland, Oregon, in which a comparison was made between yard debris, sewage sludge, and MSW composts with respect to their physical, chemical, and biological characteristics. As shown in the table, the sewage sludge compost evaluated in this particular study had relatively high concentrations of heavy metals and low levels of PCBs. In contrast, both the yard debris and MSW composts had lower levels of heavy metals, although the MSW compost had a high concentration of PCBs.

TABLE 3.5. Listing of Markets for Compost Products.

Feedstock/Location	Reference	Market	Market Status*
LEAF			
U.S. (various locations. New Jersey)	(48, 49)	General Public	A
		Topsoil Companies	A
		Nurseries	A
		Public Works & Parks Departments	A
U.S. (Cleveland, Ohio)	(46)	General Public	A
		Landscapers	A
		Nurseries	A
NSW			
Egypt (Abbis, Alexandria)	(19) a)	Large Demand (market not specified)	A
Egypt (Gisa)	(19) a)	Large Demand (market not specified)	A
France (Brametot)	(1)	Farmers	T
France (Normandy)	(26)	Artichoke fields	A
France (unspecified)	(26)	Vineyards	A
Iraq (Mosul)	(5) a)	Large Demand (market not specified)	A
Omen (Muscat)	(19) a)	No Demand	-
Qatar (Doha)	(19) a)	Municipality	A
United Arab Emirates (Abu Dhabi)	(19) a)	Municipality (70%)	A
		General Public (30%)	A
United Arab Emirates (Al Ain)	(19) a)	Farmers	A
United Arab Emirates (Sharjah)	(19) a)	Large Demand (market not specified)	A
U.S.(Broward County, Florida)	(17)	Horticulture	T
		Landscaping	T
		Blended Products	T
U.S. (Sumter County, Florida)	(50)	Nurseries	P
		Soil Amendment Dealers	P
U.S. (New York, New York)	(26)	Landfill Cover	A
MSW/SLUDGE			
Austria (Liezen)	(51)	Soil Conditioner	A
		Agriculture	
		landscaping	P
Italy (Lanerossi, Schio)	(8)	Difficult Market	*
Soviet Union (Minsk)	(38)	Horticulture	A
Soviet Union (Minsk)	(38)	Horticulture	A
Soviet Union (Minsk)	(38)	Horticulture	A
West Germany (Lemgo)	(8)	(market not specified)	-
SLUDGE			
Italy (Pesaro)	(8)	Free for Municipal Use	A
Italy (Senigallia)	(8)	Municipal Services	A
		Vegetable Growers	A
Netherlands (Halweg)	(8)	Sold (no market specified)	A
Spain (Valdemingomez)	(8)	Agriculture	A
U.K. (Canterbury)	(8)	None - Conducting trials	-
U.S. (Denver, Colorado)	(52)	Potting Soil	A
U.S. (Durham, New Hampshire)	(52)	Street & Parks Departments	P

TABLE 3.5 (Cont'd). Listing of Markets for Compost Products.

	Reference	Market	Market Status
SLUDGE (CONTINUED)			
U.S. (Columbus, Ohio)	(47)	Landscapers	A
		Nurseries	A
		Golf Courses	A
		Topsoil Suppliers	A
		Parks	A
		Cemeteries	A
		General Public	A
U.S. (Scranton. Pennsylvania)	[57)	Public Agencies (some marketed by broker)	A
U.S. (Hampton Roads, Virginia)		Street & Parks Departments	P
West Germany (Hilchenbach)	(8)	Municipal Use	A
West Germany (Horn Bad, Meinberg)	(8)	Municipal Use	A
SLUDGE/SAWDUST			
France (Nantes)	(1)	Truck Farmers	A
		Horticulturists	A
		Nurseries	A
SLUDGE/WOOD WASTE/SAWDUST			
France (Blois)	(1)	Retail Sales	A
		Large-scale farming	P
YARD DEBRIS			
U.S. (San Mateo, California)	(53)	Stockpiled for Landfill Cover	A
		Parks Department	A
		Commercial Gardeners	A
		local Agencies	A
		General Public	A
U.S. (Brookhaven, New York)	(22)	Municipal Projects	A
U.S. (Davis, California)	(54)	General Public	A
		Local Landscapers	A
		Housing Developments	A
		Commercial Construction	A
		Nurseries	A
		Small Farmers	A

A = Actual Market P = Planned T = Targeted

a) According to text, most of the plants in the Middle East now process MSW only, instead of M4 sludge; which ones are unknown.

b) Compost restricted to horticultural applications because of high heavy-metal concentrations,

TABLE 3-6. Examples of How Quality Requirements for Compost are Affected by the Needs of the Users [1].

Use	Requirements
Mushroom growing:	- fresh product (heat contribution is required) - humidity rate as low as possible, preferably below 35% of gross weight - minimal amount of inerts, if the mushroom compost is to be used in agriculture afterwards - acceptable levels of heavy metals since they tend to infiltrate mushrooms very easily
Vineyards:	- low level of "impurities" - importance of maturity and particle size will depend primarily on the intended use of the compost (maintenance or replanting) - organic content and moisture content values important for comparative costing - heavy metal content should be monitored
Arboriculture:	- clean product, low level of impurities - maturity is of lesser importance - organic content and moisture content values important for comparative costing - particle size of little significance - heavy metal content should be monitored
Truck gardening and vegetable farming:	- free of sharp items since compost spreading is often done manually - requires preferably the use of fine or very fine grade compost - maturity very important - must be absolutely free of any seeds and of any risk of phytotoxicity - salinity must be closely monitored - metal content must be monitored since metals are readily assimilated by a number of plants and may be concentrated in the edible portion of the plants
Large-scale farming:	- level of impurities important, must be free of contaminants such as plastics (visual impact) - organic matter content must be high in order to optimize the economic value of the compost - NPK fertilizing components may also be considered when calculating the economic value of the product - coarse particle size not acceptable - no fresh compost; requirements for product maturity depend on compost spreading periods - heavy metal content must be monitored

TABLE 3-7. Applicability of the Different Grades of Compost [24].

	Landfill Reclamation	Soil Amendment	Soil Amendment Larger Scale	Care of Gardens
Coarse compost	++	+	+	
Fine compost		++	++	+
Compost/sand		+	++	
"Quality compost" *			+	++

* Quality compost is defined as having characteristics that are superior to the other materials and would not present hazards to the public health. Specifics would be determined by each locale.

++ Primary application
\+ Secondary application

TABLE 3-8. Comparison Between Three Types of Composts in Portland, Oregon [23].

Characteristic	Yard Debris Compost	Sewage Sludge Compost	MSW Compost
Appearance:	Satisfactory; granular shape; relatively uniform particle size	Good, fine granular quality (based on visual inspection)	Fair; some inert matter (based on visual inspection)
Heavy metals:	Some data missing; most likely not a limitation on use of product or application rate	Relatively high concentrations; not permitted for food crop production, including animal feed stuff production	Higher concentrations than yard debris compost; not a restrictive factor
Salt concentration:	Within maximum limit for most plants	Within maximum limit for most plants	Relatively high concentration
Weed/crop seeds:	None	None	None
Germination:	Favorable	Not favorable	Not favorable
Herbicides/pesticides:	Most below detection limits	None detected	Most below detection limits
PCBs:	None detected	Low levels detected	High concentration detected
Nutrient content:	Low in nitrogen	Good	Fair

Approaches to Improve Quality

Ultimately, product quality is a function of two factors: 1) composition of the feedstock; and 2) type and thoroughness of the processing operation [8,16].

The trend in composting today is towards controlling the quality of the finished product, to the extent possible, by restricting the materials entering the compost process. For example, some compost plants in the Middle East that originally treated both MSW and sewage sludge are discontinuing the treatment of sludge because of the high salinity of sludge [19]. Similarly, because the higher concentration of heavy metals are in industrial rather than in residential sludges, one method of reducing the heavy metal content of sludge compost would be to treat only residential sludges.

Certain aspects of product quality can be affected only by controlling or adjusting the compost process itself. For example, because pathogens are intimately associated with sewage sludge, the feedstock cannot be altered to increase the quality of the compost. Instead, the number of pathogenic organisms must be reduced to a safe level in the compost product by controlling the compost process, i.e., by maintaining thermophilic temperatures in the compost mass over a sustained period. Similarly, although pesticides and herbicides in yard debris would be difficult to control through feedstock adjustment, their concentrations can be adequately reduced by way of appropriate process control.

Compost from mixed MSW typically has relatively high levels of inert materials (e.g., glass shards, scrap metal, and plastics). Unacceptable levels of heavy metals and PCBs have also been a problem in some instances. Attempts to ameliorate these problems are being made both by changing the composition of the feedstock and by altering the processing operation. Removal of contaminants by controlling the feedstock is the recommended approach, because it results in an improvement in compost quality. Moreover, market value of the product is boosted, wear-and-tear on equipment is reduced, and facility operating costs are thereby decreased [22].

The practice of source separating MSW for composting is gaining popularity world-wide [4,6,18,33-36]. In fact, Bezner (West Germany) predicts that in the future the sorting of MSW materials will be taken for granted.

He names the advantages of source separation as the following [18]:

- highest possible degree of materials separation;
- continuous supply of high grade secondary materials for the reprocessing industry;
- simple separation of undesirable and toxic waste products, including batteries, paints, lacquers, pharmaceuticals, etc.; and
- flexible adaptation to constantly changing consumer habits.

Bezner further recommends that, in addition to source separation, two processing lines be utilized to further insure product quality. A high grade of compost for garden and plant use would be produced from yard debris. A lower grade material derived from organic waste and sewage sludge would be used for road banks, playing fields, and similar projects [18].

Levasseur (France) agrees that source separation can be the best solution, but cautions, however, that its efficiency is heavily linked to public participation, type of urbanization, etc. Because, according to him, none of the existing treatment methods are fully efficient in treating all types of MSW, integrated waste management must rely on separate collection as a way to optimize the process [6].

Market analyses conducted by The German Compost Quality Assurance Organization indicate that compost from mixed MSW and from sludge is being rejected more and more frequently by potential users because of perceived high levels of toxic and inert substances. In contrast, compost produced from separately collected, exclusively organic waste, is accepted without reservation by 50% to 75% of all potential users [37].

The concern about heavy metals in compost from mixed municipal wastes is an important factor in the trend towards source separation. Baccini (Switzerland) believes that inasmuch as heavy metals must be almost entirely absent from mature compost, they must be present in limited quantity in the raw material and must be controlled in order to produce an acceptable compost. He advocates the separate collection of biological wastes (e.g., garden and kitchen wastes, land and forest products wastes, and food products industry wastes) for feedstocks to compost operations [33].

The heavy metal contents of various type of composts are presented in Table 3-9. The data in the table are indicative of the effect of various feedstocks and levels of separation on compost quality.

As is discussed in Section 6, specifications for compost quality have been developed by the CEC, ANRED, and in various countries, some Canadian provinces and some U.S. States. Specifications generally serve the following two purposes [1,8]:

- encourage producers to set processing objectives and improve the quality of their compost; and
- provide consumers with a guarantee of consistent quality and safety.

3.5.3 Developing Markets

Many approaches to compost market development have been tried, with varying degrees of success. The following aspects of market development are discussed in this section: key elements of a marketing program and importance of public education. Examples of existing practices are given.

3.5.3.1 Key Elements of a Marketing Program

An abundance of advice is available in the literature with regard to developing markets for compost products. No single approach is applicable to all situations. Differences in products as well as differences in soils, agronomic practices, social patterns, and climate create a new set of variables for each project [45].

The following is a summary of general suggestions for compost market development [15,21,27,31,45]:

- Market Research -- The fast step in developing a marketing program is to research existing and potential markets, quantify all of the markets, and develop target markets.

This requires a knowledge of the product, product use, constraints on use, and value of the product to the user.

- Product Quality -- As discussed earlier, the product should have a consistent quality. This is especially important for sales to commercial operations. The product should be geared for the market being targeted (see Tables 3-6 and 3-7).

TABLE 3-9. Actual Values of Heavy Metals in Composts (ppm, dry wt.).

Location/Feedstock	Reference	Lead	Cadmium	Chromium	Copper	Nickel	Mercury	Zinc
FEDERAL REPUBLIC OF GERMANY								
Mixed MSW	[38]	463	3.2	48	173	24	3.8	902
Source separated (kitchen/yard)	[38]	12	1		33	59		166
Source separated (kitchen/yard)	[38]	38	0.5	18	21	18		190
Source separated (kitchen/yard)	[38]	135	1.66	35	70	18		356
Yard waste compost	[39]	35.6	0.31	42.2	22.8	15.3	0.25	110
Source separated (kitchen/yard)	[39]	135	1.8	35.5	71	19.5		352.5
Mixed MSW	[8]	513	5.5	71	274	45	2.4	1570
Source separated MSW	[8]	133	1	36	33	29		408
Tree and shrub prunings, and agricultural wastes	[8]	27	<1	16	22	21	<1	80
FRANCE								
Mixed NSW	[40]	447	3.9	109	322	71	3.9	1054
Mixed MSW	[8]	527	3.2	162	127	89	3.7	886
GREECE								
MSW from urban areas and the city center	[41]	197	5.3	64	109	38		151
MSS from urban, rural and central areas with Intense trading	[41]	143	2.8	294	131	143		770
MSW from city center	[41]	140	2.4	77	121	43		729
MSW from urban areas	[41]	167	1.4	86	151	52		776
MSW from city center and areas with medium scale industrial activities	[41]	214	0.7	182	586	108		815
MSW from Athens area and other areas with high industrial activities	[41]	180	2.1	56	309	38		1308
MSW from urban areas and central part of Athens	[41]	241	7.6	80	208	41		742
ITALY								
Mixed MSW	[40]	324	4.2	108	475	33	3.1	964

TABLE 3-9 (Cont'd). Actual Values of Heavy Metals in Composts (ppm, dry wt.).

Location/Feedstock	Reference	Lead	Cadmium	Chromium	Copper	Nickel	Mercury	Zinc
JAPAN								
MSW	[4]		0.9				0.5	
Sewage sludge	[4]		2.3				0.8	
Manure	[4]		2.6				0.2	
Bark	[4]		0.2				0.3	
NETHERLANDS								
Mixed MSW	(42]	800	7	180	600	110		1700
Mixed MSW with mechanical separation of non-organics	[42]	420	1.8	40	100	25		520
Source separated HSW	[42]	150	1.0	30	50	10		230
Vegetable, fruit, and yard wastes (median)	[43]	54	0.65	55	26	11.5		175
Vegetable and fruit wastes/chipped wood	[35]	42	0.97	36	28	7.1	0.08	170
Vegetable and fruit wastes/organics	[35]	38	0.55	32	23	10	0.08	135
SOVIET UNION								
Sewage sludge/MSW	[44]	315	<5	50	130	23	10.4	12400
Sewage sludge/MSW	[44]	350	<5	250	270	70	9.9	11000
Sewage sludge/MSW	[44]	215	<5	37	140	13	20.6	11000
SPAIN								
Mixed MSW	[11]	422	3	146	225	80		350
Mixed MSW	[11]	442	4	63	145	36		394
Mixed MSW	[11]	796	6	77	738	72		972
UNITED STATES								
Yard debris	[2]	72.9	0.8	24.2	25	21	0.05	160
Yard debris	[2]	71.5	0.8	21.6	42	22.7	0.08	160
Sewage sludge (average of 10 samples)	[2]	384	26.2	288	485	126.0		1368
Mixed MSW	[2]	913	4.8	56	190	32.8	3.7	1010

- Product Testing -- The compost should be subjected to laboratory testing to ensure product quality. Field tests can also be conducted to demonstrate product utility. Often the tests are conducted by local university staff.

- Compost Samples -- Prospective clients should be provided with compost samples and specification sheets.

- Product Labelling -- All products should be shipped along with a description of the product. This description should include results of laboratory tests.

- Reliable Supply -- Commitments to buyers must be fulfilled.

- Diversity -- Production of a variety of products broadens the potential market base.

- Market Location -- Due to the relatively low economic value of the material, its low bulk density, and its high moisture content, transportation costs of compost sold in bulk form can be prohibitive to market development. Therefore, local markets should be sought. Sales beyond 80 kilometres generally are not economically feasible for bulk compost unless specialized, high-graded mixes are made. Transportation constraints are not as rigorous for the packaged retail market.

- Product Identity -- A positive identity which becomes familiar to the public is an important factor in successful mass marketing of a compost. A trade name is needed that connects the product to the area, or with a popular area feature.

- Prospects — Sound rule of thumb of marketing is to have good prospects for at least twice the production.

- Continuing Effort -- Aggressive marketing is necessary to assure that all product is utilized and that revenues are optimized.

- New Markets -- Work on developing new markets. This may include working with landscape architects on developing specifications for use, or with government agencies regarding use in highway construction and maintenance.

Marketing services can be contracted out. For example, in the United States, many New Jersey towns have hired private firms to manage their leaf compost programs. The participating municipality supplies publicly-owned sites, equipment, and operators. The company provides technical and management support, site supervision, and marketing services for the compost [32].

Another approach to compost marketing that is becoming increasingly popular is to market the product through a broker. The broker buys the compost at a low price, takes responsibility for product testing, compliance with regulatory constraints, and promotion. The compost can be marketed alone or as a component of a series of mixes [21].

3.5.3.2 Public Education

Public education is an important facet of a compost marketing program. Because the product is derived from waste material (whether it be MSW, sewage sludge, yard debris, or animal manure), the product has a stigma that acts as a barrier to market development. This barrier cannot be avoided, but it can be overcome using consumer education and demonstration of product value [2,27,45].

Results from a market study conducted in the metropolitan area of Portland, Oregon, provide an example of the stigma that can be attached to compost produced from recycled wastes. In the study, residents were questioned regarding their feelings about using any one of three compost products, namely, yard debris, sewage sludge, and MSW. Of the residents surveyed, over one-third expressed some concern about using any of the composts or with one of the composts in particular. Although most of the residents indicated they were familiar with the products, most of their concerns were directed at all three composts. Some of the more frequently mentioned concerns were [2]:

Disease transmission
Contamination, chemicals, hazardous wastes
Harmful to children or pets
Harmful to plants
Dislike of human wastes in yard
Dislike of garbage in yard
Odour
Flies and mosquitos
Health concerns
Heavy metals in sewage sludge
Safety for edible produce
Uncertainty as to contents
Cleanliness
Appearance

3.5.3.3 Examples of Existing Marketing Programs

The following are examples of approaches utilized by individual programs to market compost.

3.5.3.3.1 The Greater Cleveland Ecological Association

Three approaches have been proven successful in marketing compost produced from yard debris in the Cleveland, Ohio (U.S.) area [46]. They are:

1. Bag and bushel program -- Small scale gardeners bring their own containers and pay 88 cents per generous bushel. Market is open five months (April through June, and September through October).

2. Bulk load pickup -- Facility personnel load the customer's truck and charge $ 20/m^3.

3. Home delivery -- This is the most popular approach and accounts for 60% to 70% of the compost sold. A local topsoil dealer does the hauling. Home delivery is available four days a week during the spring, summer and fall. The minimum residential sale is 1.5 maximum is 8 m^3. The charge is $77 for 1.5 m^3 of regular grade compost, and $ 274.40 for 8 m^3, including delivery charge and taxes. For out-of-county delivery, there's an added $ 23.50 charge. Semi-truckloads delivered to landscapers and commercial growers are sold at a discount to encourage the use of composted materials on lawns and in potting medium for nursery stock.

The Association has also utilized publicity to promote the program. The publicity includes: 30 to 40 publicity stints a year on TV shows, articles in newspapers, and newsletters emphasizing the ecological benefits of the compost.

3.5.3.3.2 Oman (Middle East)

There is a strong demand for high quality organic fertilizers in the agricultural country of Oman. A market study for the end product was conducted prior to construction of the plant. The study demonstrated that 12,000 tonnes/yr could be marketed, assuming a high quality compost was produced [10]. The finished product was tested for pathogens and parasites. Twelve people were employed for the marketing and distribution of the compost. Oman is a country with a very low population density of about 5 people/km^2. Consequently, farms are spread out and distribution costs are high. The following breakdown of production costs demonstrate the amount allocated to selling and distribution:

Processing costs	30%
Administrative costs	8%
Selling and distribution costs	24%
Depreciation	20%
Interest on loans, etc.	8%

3.6 References

3.6.1 Technologies

[1] Tonge, Peter, "Green Grows Garbage," The Christian Science Monitor (March 1, 1988).

[2] "Waste Plant to Turn Garbage Into Soil, The Gastonia Gazette (July 14, 1988).

[3] Marques, Aminda, "Firm Tums Trash into Plant's Delight," The Miami Herald (May 25. 1989).

[4] Reveron, Derek, "Agripost's Decade of Work Starts to Pay Off," The Miami Herald (November 14, 1988).

[5] Goldstein, Nora, "A Guide to Solid Waste Composting Systems," BioCycle, 30(1):38-47 (January 1989).

[6] "Regional Roundup," BioCycle, 29(7):11-14, 19-25 (August 1988).

[7] Noffsinger, Jan, "Sumter County Showcases State's First Volume Reduction Facility." Solid Waste News Report, 1(2) (Fall Quarter 1988).

[8] Environmental Recovery Systems, Inc. Informational Proposal.

[9] "Solid Waste Disposal: Avoiding a Crisis," Environmental Recovery Systems, Inc.

[10] "Proven, Practical Waste Processing Systems," Buhler Miag, 1989.

[11] "Waste Processing Systems," Buhler Miag, 1989.

[12] "Economical Recycling of Refuse and Sewage Sludge," Buhler Miag.

[13] Personal communication with Luigi Castelli, Daneco, Inc. (July 1989).

[14] Correspondence from W.L. Carlin, WPF Corporation (June 22, 1989).

[15] "Solid Waste Disposal Recycling Process," WFP Corporation.

[16] "Process Description," American Bio Tech.

[17] "American Recovery Corporation: Conserving the Nation's Resources with Proven Technology."

[18] "American Recovery Corporation: Sorain Cecchini Technology."

[19] Correspondence from John B. Nutter, American Recovery Corporation (July 6, 1989).

[20] Communication with Jack O'Brien, Ashbrook-Simon-Hartley (July 1989).

[21] "Information on the Company's Technology for Large-Scale Co-Composting of Municipal Solid Waste and Sewage Sludge," Bedminster Bioconversion Corp.

[22] "The Cost Effective Alternative to Sludge Disposal Problems," Compost Systems Co.

[23] "The Paygro System Enclosed Dynamic Composting System," Compost Systems Co.

[24] "The Dynatherm Modular Composting System," Compost Systems Co.

[25] "Fairfield Composting Process," Fairfield Engineering Co.

[26] "Fairfield Digester System," Fairfield Engineering Co.

[27] "Fairfield Resource Recovery Process," Fairfield Engineering Co.

[28] "The Composting Specialists," International Process Systems.

[29] "In-Vessel, Fully Controlled Composting Systems for Agricultural, Industrial, and Municipal Organic Wastes," International Process Systems.

[30] "The Siloda Process," OTV.

[31] Mousty, P. and J.P. Levasseur, "The Silorco-Siloda Process," Resources and Conservation, 14:309-320 (1987).

[32] "PURAC Bioreactor Composting: The ABV Systems," PURAC Co.

[33] "PURAC In Vessel Composting Systems," PURAC Co.

[34] "The Enclosed Dynamic Composting System from Royer," Royer.

[35] "The Taulman/Weiss Composting System: The Worldwide Leader for In-Vessel Composting Systems," Taulman/Weiss.

[36] "St. Palais, France: Sewage Sludge Accelerated Composting Plant," Harbert/Triga.

[37] "The World of Waste Treatment," Dano.

[38] Riedel Waste Disposal Systems, Inc., Company Brochure, July 1989.

3.6.2 Economics of Composting

[1] Den, D.A., The Economics of Leaf Composting, Rutgers, State University of New Jersey, p. 4, 1985.

[2] Goldstein, N. "Problem Solving At a First Generation Facility," Biocycle, 29(8):30-32 (September 1988).

[3] Craig, N. "Solid Waste Composting Underway in Minnesota," Biocycle, 29(7):30-33 (August 1988).

[4] Gorham, D. and R. Zer, "Portland Moves to Solid Waste Composting," Biocycle, 2(7):34-37 (August 1988).

[5] Elliott, IC. and A.J. Polidori, "Scranton Expands Compost Facility," Biocycle, 29(1):44-48 (January 1988).

[6] Cerenzio, Peter, F., "Turnaround in Sussen County," BioCycle, 28(4):26-28 (April 1987).

[7] "Racetracks Bet on Composting," Biocycle, 2(3):38-39 (March 1988).

[8] Johnson, J., J.F. Donovan, and A.B. Princince, "Operating & Cost Data for In-Vessel Composting," Biocycle, 30(4):40-43 (April 1989).

[9] Spielman, B., "A Yard Waste Primer," Waste Age, 29(2):44-52 (February 1988).

[10] Goldstein, N., "Technology Evolution at Compost Sites, " Biocycle, 28(10):28-33 (November-December 1987).

[11] "Agripost News Construction of Compost Facility," Biocycle, 29(10):13-14 (November-December 1988).

[12] Logsdon, G., "Calculating Costs of Leaf Composting," Biocycle, 29(9):43 (October 1988).

[13] Swift County Solid Waste Compost/Recycling Project, prepared by Cal Recovery Systems, Inc., for Swift County Auditor, Benson, Minnesota, March 1988, updated November 1988.

[14] Taylor, A.C. and R.M. Kashmanian, Study and Assessment of Eight Yard Waste Composting Programs across the United States. Office of Policy, Planning, and Evaluation, U.S. Environmental Protection Agency, EPA/530-SW-89-038, 1988.

[15] Benedict, A.H., *et al*, "Municipal Sludge Composting Technology Evaluation, Journal WPCF, 58.(2) (April 1986).

[16] El-Halwagi, MM., *et al*, "Assessment of the Performance of MSW Composting Facilities under Egyptian Conditions," Resource Conservation and Recycling 1:97-109, 1988.

[17] Taulman/Weiss, "The Taulman/Weiss Composting System: The Worldwide Leader for In-Vessel Composting Systems."

[18] Compost Systems Company, "The Paygro System Enclosed Dynamic Composting System."

[19] Kasper, V. and Derr, D.A., Sludge Composting and Utilization: an Economic Analysis the Camden

Sludge Composting Facility. New Jersey Agricultural Experiment Station, Rutgers College, New Brunswick, New Jersey.

[20] Alpert, J.E. and Johnson, P. "Cost Analysis of Static Pile Composting in the United States," Proceedings of the International Conference on Composting of Solid Wastes and Slurries, University of Leeds, Leeds, England, September 1983.

[21] Chertow, M.R. Garbage Solutions. National Resource Recovery Association and U.S. Conference of Mayors, Washington, D.C., 1989.

[22] Project Report: 1983-1986 Pilot Compost Program, East Bay Municipal Utility District, Oakland, California, June 1987.

[23] Feasibility Evaluation of Municipal Solid Waste Composting for Santa Cruz County, California, prepared by Cal Recovery Systems, Inc. for Santa Cruz County and the California Waste Management Board, December 1983.

3.6.3 Marketing Compost Products

[1] de Lauzanne, R., "Methodologies and Technologies in Compost Production: The French Experience," presented at the International Symposium on Compost Production and Use, S. Michele All'Adige (Trento), Italy, June 1989.

[2] Portland Area Compost Products Market Study, prepared by Cal Recovery Systems, Inc. for the Metropolitan Service District, Portland, Oregon, October 1988.

[3] Mays, A., and P.M. Giordano, "Landspreading Municipal Waste Compost," BioCycle, 30(3):37-39 (March 1989).

[4] Kubota, H., and K. Nakasaki, "State of the Art of Compost Systems: The Current Situation and Future Outlook in Japan," presented at the International Symposium on Compost Production and Use, S. Michele All'Adige (Trento), Italy, June 1989.

[5] Shimell, Pamela, "Refuse Derived Compost Boosts Vineyard Yields," World Wastes, 26(11):8-9 (November 1983).

[6] Levasseur, J.P., "Household Refuse Recycling in France," BioCycle, 29(6):32-33 (July 1988).

[7] Porter, Colin, "French Farmers Favour Cordon Bleu Compost," Surveyor, pgs. 14-16(September 1981).

[8] L'Hermite, P., "State-of-the-Art of Composts Systems: Current Situation in Europe and Future Outlook," presented at the International Symposium on Compost Production and Use, S. Michele All'Adige (Trento), Italy, June 1989.

[9] Robotti, A., G. Ramonda, A. Nassisi, A. Rattotti, and A. Barilli, "Optimization of Composting Process Utilizing Urban and Agricultural Wastes," pp. 666-675, Compost: Production, Quality and Use, M. de Bertoldi, M.P. Ferranti, P. L'Hermite, and F. Zucconi, eds., Elsevier Applied Science, 1987.

[10] Dhingra, V.K., and J.P. Levasseur, "An Example of Private Venture in Household Refuse Composting," Proceedings of the International Symposium on Environmental Management: Environment '87, Istanbul, 1987.

[11] Sana, J., F. Giro, M. Sofiva, and P. Florensa, "Approccio Metodologico Nella Valutazione della Qualita del Compost della Catalogna, Spagna," presented at the International Symposium on Compost Production and Use, S. Michele All'Adige (Trento), Italy, June 1989.

[12] Naylor, L.M., G.A. Kuter, and D.J. Hagen, Shredded Magazines and Glossy Paper as a Bulking Agent: Composting Demonstration Trial, prepared by International Process Systems, Inc., May 1989.

[13] Spaggiari. G.C., G.L. Spigoni, R. Jodice, and M. Consiglio, "Transformation of Urban Sludges Mixed with Grape Stalks into Organic Fertilizers," pp. 100-109, Compost: Production. Quality and Use, M. de Bertoldi, M.P. Ferranti, P. L'Hermite, and F. Zucconi, eds., Elsevier Applied Science, 1987.

[14] Gerrits, J.P.G., "Compost for Mushroom Production and its Subsequent Use for Soil Improvement," pp. 431-439, Compost: Production. Quality and Use, M. de Bertoldi, M.P. Ferranti, P. L'Hermite, and F. Zucconi, eds., Elsevier Applied Science, 1987.

[15] Yard Waste Programs and Policies for Carver County, prepared by John and Michele Genereux, January 1989.

[16] Composting Technologies, Costs. Programs. and Markets, prepared by Cal Recovery Systems, Inc. for the Congress of the United States, Office of Technology Assessment, Washington, D.C., January 1989.

[17] Goldstein, N., "Key Issues in Solid Waste Composting," BioCycle, 29(9):29-34 (October 1988).

[18] Bezner: Maschinen aus Ravensburg," Maschinenfabrik Bezner, Ravensburg, West Germany.

[19] Hughes, E. Glynn, "Performance of Compost Plants in the Middle East," BioCycle, 30(7):36-38 (July 1989).

[20] Levassseur,"Recycling of Household Refuse by Siloda and Silorco Processes,"Centre Francais du Commerce Exterieur, 1985.

[21] Yard Waste Management Action Plan for San Jose. California: Final Draft Report, prepared by John Madole Associates, March 1988.

[22] O'Brien, J.K., "Prospects for Year-Round Composting of Municipal Yard Waste," Resource Recovery, pgs. 26-27 (February 1989).

[23] Eggerth, L.L., L.F. Diaz, and S. Gurkewitz, "Market Analysis for Multi-Compost Products," BioCycle, 30(5):29-34 (May 1989).

[24] Tomer, Lars, "Marketing Possibilities for Compost."

[25] Geilinger, M., "Municipal Composting - A Practical Model," Phoenix International, 109:28-33 (February 1987).

[26] Pollack, *C.,* "Mining Urban Wastes: The Potential for Recycling," Worldwatch Paper 76, April 1987.

[27] Feasibility Evaluation of Municipal Solid Waste Composting for Santa Cruz County, California, prepared by Cal Recovery Systems, Inc. for Santa Cruz County and the California Waste Management Board, December 1983.

[28] Kuter, G., and L. Naylor,"Compost for Nursery Crops."

[29] Naylor, L. and G. Kuser, "Compost for Turfgrass and Landscaping "

[30] "Compost Markets: California DOT Says More Study Needed Before Use." Waste Age, 20(3):195 (March 1989).

[31] Salimando, J., "Woodhue Compost ... or Wouldn't You?" Waste Age, 20(5):63-66 (May 1989).

[32] Chertow, M.R. Garbage Solutions: A Public Official's Guide to Recycling and Alternative Solid Waste Management Technologies, 1989.

[33] Baccini, P., and P.H. Brunner, "Sortierung in der Abfallwirtschaft: Wie gross ist ihr Beitrag zu einem ressourcenschonenden und umweltvertraglichen Stoffhaushalt?" Gas. Wasser. Abwasser, 68(11):617-622 (1988).

[34] Mayer, M., H. Hofer, and U. Maire, "Trends in Yard Waste Composting," BioCycle, 29(6):60-62, (July 1988).

[35] Roosmalen, G.R., and J.C. van de Langeerijt. "Green Waste Composting in the Netherlands," BioCycle, 30(7):32-35 (July 1989).

[36] Golueke, C.G., and L.F. Diaz, "Quality Control and Waste Management," BioCycle, 30(7):65-67 (July 1989).

[37] Funke, U., "Marketing Problems," presented at the International Symposium on Compost Production and Use, S. Michele All'Adige (Trento), Italy, June 1989.

[38] Funke, U., "Economics from Household to Compost Through a Complete System in the Federal Republic of Germany," presented at the International Symposium on Compost Production and Use, S. Michele All'Adige (Trento), Italy, June 1989.

[39] Stegmann, R., and U. Krogmann, "Composting of the Organic Fraction of Municipal Solid Wastes Separated Through Selected Collection," presented at the International Symposium on Compost Production and Use, S. Michele All'Adige (Trento), Italy, June 1989.

[40] Krauss, P., R. Blessing, and U. Korherr, "Heavy Metals in Compost from Municipal Refuse: Strategies to Reduce Their Content to Acceptable Levels," pp. 254-265, Compost: Production. Quality and Use, M. de Bertoldi, M.P. Ferranti, P. L'Hermite, and F. Zucconi, eds., Elsevier Applied Science, 1987.

[41] Kapetanios, E., M. Lodzidou, and E. Matiou, "Heavy Metal Levels and Their Toxicity in Composts from Athens Household Refuse," Environmental Technology Letters, 9:799-802 (1988).

[42] Oosthock.J., and J.P.N. Srnit, "Future of Composting in the Netherlands," BioCycle, 28(6):37-39 (July 1987).

[43] Lustenhauwer, H.W.A., *et al*, "Source Separation and Collection of Compostables," BioCycle, 28(6):33-36 (July 1987).

[44] Peterson, C., and A. Perlmutter, "Composting in the Soviet Union," BioCycle, (7):74-75 (July 1989).

[45] Albrecht, R., "How to Succeed in Compost Marketing," BioCycle 28(8):26-27 (September 1987).

[46] Logsdon, G., "A Business-Like Approach to Leaf Composting," BioCycle, 30(3):22-24, (March 1989).

[47] Walter, Scott, "Is There a Market for Compost?"

[48] "Options for Municipal Leaf Composting," BioCycle, 2(9):38-43 (October 1988).

[49] Meade, K., "Waiting for the Leaves to Fall," Waste Alternatives/the Disposal Crisis.

[50] Personal communication with M. Olson, U.S. Waste Recovery (May 1989).

[51] "Refuse Hygienization Plant for Liezen: Solution Towards a Clean Future," Voest-Alpine AG, Austria.

[52] Goldstein, N., "Compost for Sale," BioCycle, 28(8):25 (September 1987).

[53] Bergeron, A.T., "Recycling Plant Materials," BioCycle, 29(2):29 (February 1988).

[54] Gertman, R., "Davis Waste Removal Company Compost Program."

4.0 EVALUATION OF REPRESENTATIVE NORTH AMERICAN FACILITIES

4.1 Operating and Proposed Composting Facilities in Canada

Several communities in Canada are investigating the feasibility of municipal composting programs. A few municipalities have implemented leaf composting programs and back yard composting programs and two Canadian municipalities have programs to handle household organic wastes at a centralized facility. A brief summary of some of the existing and proposed composting activities is outlined below.

4.1.1 Municipal Programs Riley, Alberta

The community of Riley started a composting project in June 1989. Residents are provided with a small garbage can to collect household organics and a large can to collect outdoor organic yard wastes. Approximately 95% of the households in Riley participate and are currently diverting about 100 tonnes per year from the landfill.

Amos, Quebec

This facility has been operating since the Fall of 1988. The mixed municipal waste is hand sorted for recyclable material. The organics are composted in windrows. The facility has a capacity of 3600 tonnes per year.

Rawdon, Quebec

A composting and recycling plant will be operational in Rawdon in October 1989. The plant will serve four communities and have a capacity of 30,000 tonnes per year. The plant will cost approximately $3 million. The processing includes manual recovery of paper, plastic and glass followed by magnetic separation for ferrous metal. The remaining residue will be composted in two tunnel reactors. Septic sludge may be added to the process.

Essex-Windsor, Ontario

Essex-Windsor plans on developing a composting program that will potentially accept residential food and yard waste, industrial/commercial organic waste and sewage sludge. The initial processing facility will have a capacity of at least 50 tonnes per day and provisions for expansion to at least 100 tonnes per day. A modified windrow system will be used to process the compost.

City of Windsor, Ontario

The City of Windsor is composting approximately 20,000 tonnes per year of municipal sewage sludge. The sludge is mixed with wood chips and shredded rubber tires as bulking agents.

The sludge is composted using the forced aeration static pile method for 30 to 40 days. It is then screened and cured in another forced air static pile.

Most of the compost is used by the City's Parks Department. Some is sold to greenhouses.

Metro Toronto, Ontario

Metro Toronto is selling 12,000 backyard composting units to interested residents at a quarter of the actual cost of the unit. Metro believes that the household composting program will pay for itself in five years by avoided collection and disposal costs.

Metro Toronto will also be starting a pilot project to collect organic yard wastes from the curb. The pilot will include 10,000 households and 30,000 tonnes of organic wastes are expected to be diverted. Participating households will be given clear, non-biodegradable plastic bags for the collection of glass clippings, hedge clippings and other miscellaneous organic yard wastes. Residents will be asked to bundle brush separately. Collected yard wastes may be composted at existing leaf composting facilities if the Certificates of Approval can be amended.

Recommendations from a preliminary study on European composting systems will be presented to Metro Toronto in September 1989. A 190 tonnes/day composting facility may be built to handle commercial organic wastes. Waste sources may be supermarkets, restaurants and food processors.

City of Peterborough. Ontario

The City of Peterborough is interested in implementing a composting program. The City has not yet determined what program type or strategy will be used. A system study will be carried out in 1988-1989.

Region of Halton, Ontario

Halton is encouraging its residents to compost their organics in the backyard. The Region provides information on how to build or where to buy composter bins. The Region is interested in implementing a wet/dry collection process and may start a pilot program in the fall of 1989. Program specifics have yet to be finalized.

Hamilton-Wentworth, Ontario

A 30,000 tonnes/year facility will be built adjacent to a solid waste transfer station. Organics will be screened from the mixed waste stream using mechanical and hand sorting. The organics will be composted with sewage sludge from a nearby waste water treatment plant in a high rate vessel system. The Region is hoping to go to tender for the facility in the Fall of 1989.

City of Guelph, Ontario

A wet/dry recycling pilot program will commence in August 1989. The pilot study is expected to last two years. The study area will be divided into three groups:

Group A
- wet waste in green bin
- recyclable dry waste in blue bin
- non-compostable and non-recyclable waste in regular garbage bags

Group B
- wet waste in green bin
- recyclable and non-recyclable dry waste in regular garbage bags

Group C
- wet waste in green bin
- recyclable and non-recyclable dry waste in blue bin

The wet waste will be composted at a pilot plant. University of Guelph faculty members will assist the City by running field trials and tests on the compost.

Region of Peel, Ontario

The Region of Peel will be commencing a composting pilot project once they receive a Certificate of Approval from the MOE. A study area of 1,206 homes has been selected. The area will be divided into three groups with different containers to bring the organics to the curbside.

- Group 1 will be provided with a 17 gallon "Rubbermaid" curbside container,
- Group 2 will be provided with a 10 gallon "Rubbermaid" curbside container, and
- Group 3 will be provided with a poly-tie plastic bag.

Each household will be provided with a "Kitchen Catcher" container and green "Kitchen Catcher" bags. Once the bags are full they will be placed in the large curbside container. All yard waste will go in the large curbside container. If the curbside container is filled, additional poly-tie bags will be provided. The organic wastes from the pilot project will be composted by Grow Rich Fertilizers Ltd. (See 4.1.2 below).

4.1.2 Private Sector Composting Initiatives in Ontario

Several private sector companies in Ontario are planning to develop composting systems. Some private sector initiatives are briefly outlined below.

WCI Waste Conversion Inc.

WCI Waste Conversion Inc. are planning to construct a composting facility at their Waste Wood Recycling plant in Brampton, Ontario. The company is also the designer of the Hamilton-Wentworth Regional composting facility recently partially funded by the Ontario Ministry of the Environment. The latter facility will be a 30,000 tonnes/year high-rate aerobic composting facility incorporating the WCI channel system.

Grow-Rich Fertilizers Ltd.

Grow-Rich is presently operating a 70,000 tonnes/year composting facility in the Niagara Region. Grow-Rich accepts organic papermill sludges and wastes from local industries and sells the compost to garden centres, landscapers, land reclamation projects and greenhouses. Grow-Rich is assisting the Region of Peel with a municipal organic waste composting pilot project. Grow-Rich offers turn-key systems to industry for the composting of their wastes and markets the product for its own account.

Philip Environmental

Philip Environmental in Hamilton, Ontario is experimenting with high rate-high volume composting systems using an aerated agitated bed. They plan on providing municipalities and industries with turn key, privately operated or owner operated facilities.

Loamcrafters Inc.

Loamcrafters Inc. is a new Toronto-based company that has recently been formed to commercially compost sludges and yard wastes.

4.2 United States

4.2.1 Introduction

The formidable combination of a shortage of land available for landfilling, dramatic raises in tipping fees, and the imposition of increasingly restrictive legislative measures has led to a revival of composting as a viable alternative for waste management in the United States. Corn-posting is currently utilized in the U.S. to process MSW, sewage sludge, yard debris, and other organic wastes.

Composting *was* given consideration as a solid waste treatment process in the U.S. as early as the 1950s. However, a number of factors in the late 1960s combined to discourage the prospects for composting MSW: 1) the high carbon-to-nitrogen ratio of mixed refuse in the U.S.; 2) an absence of a market; and 3) the low cost of landfilling.

A rekindling of interest in composting arose in the early 1970s as a method to dispose of sewage sludge. It was not until the end of the 1970s and the beginning of the 1980s that composting again began to be seriously considered as a viable option in the U.S. for the management and disposal of municipal solid waste. At the present time, however, composting and co-composting of MSW and sludge are receiving considerable attention. This is attested by the fact that as of this writing, five full-scale MSW composting facilities are in operation, and at least thirty facilities are in the construction, planning, or negotiation stages.

The desperate shortage of landfill capacity has prompted a closer scrutiny of all residues coming to the landfill site and of their suitability to composting. It was soon realized that yard and garden debris are very amenable to composting. As a result, hundreds of facilities to compost these wastes have become operational in the U.S. [1]

4.2.2 Sewage Sludge

Composting as a sludge management and disposal option received little attention until the early 1970s. By that time, waste generation had accelerated at a rate such that available landfill space was shrinking at an alarming rate. Moreover, a mounting concern about environmental quality and public health began to be manifested by tighter restrictions on all aspects of landfilling. Regulations regarding landfill disposal of sewage sludge were made even more stringent than for municipal solid waste.

The combination of land shortage and environmental and public health concerns prompted a serious exploration of options other than landfill for the disposal of sludge. Although at first, incineration seemed to be an attractive option, later developments brought to light serious problems, not the least of which are the very high costs involved. In addition, the solid and gaseous emissions from sludge incineration require careful and expensive control measures. Consequently, composting began to appear increasingly attractive in terms of the environment, public health, and economics.

The spread of composting as a sludge management practice began primarily in the northeastern part of the U.S. The number of operational sludge composting plants has risen dramatically during the years 1983 through 1988, from 61 to 115 [2].

4.2.2.1 Systems, Numbers, and Status

The types of sewage sludge composting facilities in operation in 1988 are listed in Table 4.1. According to the table, the static pile technology is the most widely represented, with 61 operational facilities.

The number of facilities using the turned-windrow technology is less than one-half that of facilities using the static pile system, i.e., 29 as compared to 61. The in-vessel approach ranks third in terms of number of facilities with 19. The extent of sludge composting practice in the U.S. in 1988 is indicated by the data listed in Table 4-2. According to the data the number of facilities in operation at that time exceeded the total number of those in the pre-operational stages, i.e., 115 operational vs. 104 pre-operational. If all of the facilities in pre-operational stages were to progress to the operational stage, the total number of active facilities would be 219. Even so, the amount of sludge being landfilled would substantially surpass the amount subjected to composting.

TABLE 4-1. Types of Operational Sewage Sludge Composting Facilities in the U.S. as of 1988 [1].

Type	Number
Aerated static pile	61
Turned windrow	29
In-vessel	19
Aerated windrow	5
Vermicomposting	1
Total	115

TABLE 4-2. Status of Sewage Sludge Composting Projects in the U.S. as of 1988 [1].

Status	Number of Projects
Operational	115
Pilot	14
Under construction	14
Planning, design	40
Consideration	36
Total	219

The smaller number of in-vessel facilities presently in operation may be explained by cost factors and some operational difficulties. However, the number of in-vessel facilities in the consideration, planning, and design stage is greater than that of any of the other systems. Among the reasons offered for the apparent preference for in-vessel systems are: 1) site constraints; 2) expected satisfactory process and odour control; and 3) projected lower labour costs. However, the validity of these reasons is as yet to be conclusively demonstrated since operators of in-vessel systems have experienced problems with odors as well as mechanical breakdowns.

As for experience with turned windrow systems, it too has not been free from odour and operational difficulties. These difficulties have been attributed to climatic factors (e.g., excessive rainfall, snow, and freezing temperatures). Some facilities have placed most of their operation in enclosed structures in order to alleviate the problems resulting from inclement climate. Problems involving the release and control of unpleasant odors are common to both in-vessel and windrow systems.

4.2.2.2 Odours

A major problem confronting the sludge composting industry today is generation and escape of foul odours. It also is the most difficult to solve or at least, to control. Consequently, many research and development programs aimed at finding effective ways of controlling odours have been proposed and conducted. Because it was felt that the causes of foul odours generation are well known, the approaches investigated in the programs were designed to contend with the odours rather than to prevent their generation. An unfortunate result has been that insufficient attention is directed to the prevention of the generation of malodors through appropriate process control. Among the odour treatment approaches that have been investigated are wet scrubbing, use of biological filters, and the addition of lime.

4.2.2.3 Future

Unlike the unsuccessful ventures in composting MSW in the late 1950s and early 1960s, composting has developed into a sound and cost-effective method of treating municipal sewage sludges. Nevertheless, for the success to continue into the 1990s, two, or possibly three, obstacles must be overcome. The first of the obstacles is mostly associated with the degree of development of the industry as a whole, in that capacities for some systems as *yet* are not well defined. The second obstacle relates to certain shortcomings in the quality of the sewage sludge compost product. For example, the pervading variability of physical characteristics, of moisture content, and of concentrations of nutrient chemicals constitutes an impediment to many agricultural applications and to marketing the product in general. However, a potential obstacle much more serious than the preceding two is the presence of hazardous substances (heavy metals and toxic organic compounds) in the product. Fortunately, this obstacle applies mostly to the composts produced by wastewater treatment plants that combine the treatment of industrial and residential sewage. Since industrial sewage contributes the greatest share of the hazardous substances, a potential solution to this obstacle is to pre-treat industrial waste waters that contain toxic compounds prior to discharge. By instituting source prevention, the quantities of toxic substances entering the waste stream can be significantly reduced.

A fairly recent development is the search for substances that can satisfactorily replace wood chips and sawdust as bulking agents. The search is prompted in part by the rising cost and frequent unavailability of the two wood wastes. Among the materials that have been used are shredded tires, plastics, yard debris, and certain field crop residues.

4.2.2.4 Summary

Composting of sewage sludge in the U.S. did not become popular until the early 1970s. The popularity was brought about by the increased production of sludge, combined with the increased costs of alternative disposal methods. Implementation of sludge composting projects was accelerated by the stringent regulations controlling landfill disposal of sewage sludge. The number of sludge composting facilities nearly doubled between 1983 and 1988 (i.e., from 61 to 115).

The majority of the composting facilities use windrows, particularly the static type. It is expected that the number of in-vessel systems will increase in the next few years. This is attributed to the concern about odors and area requirements.

One of the most serious problems facing the sludge composting industry is odor containment and control. In addition, in-vessel facilities have had a number of materials handling problems.

Most sewage sludge composting facilities use sawdust or wood chips as bulking agents. However, due to the cost of the forest products, facility operators have been actively searching for materials that can be substituted for them. Some of these materials include shredded tires, plastics, yard debris, and the organic fraction of MSW.

Sewage sludge composting is not widely practiced in the countries that were surveyed. The main exception is Japan where it has been reported that there are 31 plants in operation. Regulations imposed on landfilling and land application are expected to increase the number of sewage sludge composting plants.

4.2.3 Municipal Solid Waste

Circumstances that in the 1970s served as an impetus to sewage sludge composting and led to its eventual widespread application are now combining to do the same for the organic fraction of MSW. As had been the case with sewage sludge disposal, in the 1980s, landfill shortages, high disposal fees, and legislative prohibitions regarding the disposal of unprocessed MSW on the land are increasing the attractiveness of the composting option. The option is made even more attractive by the availability of financial assistance programs in some states (e.g., Massachussetts, Minnesota, and Iowa). Recently, several states have passed legislation regarding alternatives for managing solid wastes. Typically, the laws establish a hierarchy of alternatives in which recycling, composting, and reduction in waste generation are at the top, and incineration and landfilling are at the bottom. Finally, the U.S. Environmental Protection Agency recently proposed new regulations for landfills that certainly would increase the monetary cost of land disposal, thereby enhancing the appeal of composting.

The current high level of interest in MSW composting is not without its dangers. In some cases, the process is being chosen without having conducted an adequate analysis of alternatives or having considered certain problems and costs that come with composting MSW.

The problems and costs mentioned in the preceding paragraph are due to the fact that composting municipal solid wastes is a complex undertaking. The degree of the complexity depends upon the level and type of separation that must be carried out at the facility. Because of the amounts of material involved and sharp time limitations, separation at the facility is almost invariably done mechanically. The problem is that, of the several steps in the processing of MSW to form a feedstock for composting, mechanical separation poses the highest challenge. Finally, it is again emphasized that the quality of the finished product is largely dependent upon the type, efficiency, and thoroughness of the separation process [3,4].

4.2.3.1 Facilities in Operation

As of 1988, there were five MSW compost facilities in operation in the U.S. (see Table 4-3). As the data indicate, capacities represented by the facilities range from about 13 to 900 tonnes/day. Other than the plant in Wilmington, Delaware, the composting facilities are relatively small and simple, and began operation within the past three years.

Judging from personal observations and information obtained in discussions with designers and operators, existing compost facilities in the U.S. generally are characterized by a relatively low capital investment, limited throughput, and an over-simplified design (see Section 3.4 on economics of composting). The composting phase is emphasized, whereas the attention directed to the segregation of organic from inorganic matter is less than would be desirable. Similarly, the use of finished product is not receiving the attention it warrants.

Wilmington. Delaware

The Wilmington plant is designed to process about 900 tonnes of municipal and commercial solid waste per day. Processing includes size reduction, air classification, magnetic separation, and screening to recover metals and glass and to produce a refuse-derived fuel (RDF). In addition to the recovery and the RDF production, the process also generates about 227 tonnes of highly organic residue. The residue is mixed with an equal amount of sewage sludge (total solids, about 20%) and is then deposited into one of four reactors. Each of the reactors has a capacity of 159 tonnes. The material is held in the reactor for about five days, during which time it is mixed and aerated.

Analysis of the compost produced by the plant, indicated that the product had concentrations of PCBs in the range of 4 to 5 ppm. Such concentrations ruled out the original plan to market the product as poultry litter. Current plans are to market the product for use in horticulture.

Sumter County. Florida

A windrow composting operation located in Sumter County has been on-line since mid-1988. Operators of the facility state that 65 to 70 tons of residential and commercial wastes are received each day. Treatment is begun by passing the wastes through a flail designed to break open bags and packages, thereby allowing their contents to mingle with the waste stream. The waste stream is then subjected to magnetic separation to remove ferrous metals. Aluminum and some inerts are removed manually. The waste stream is then size-reduced to an approximate 5 x 5 cm. particle size and transferred via trucks to the windrow area. It is then stacked to form a 1.8 m high by 3 m wide windrow. A bacterial implant is added. Operators indicate that the compost is ready to be marketed after six weeks.

As of May 1989, no finished compost had been marketed. According to the operators of the facility [5], they are planning to sell the material to nurseries and soil amendment dealers. However, marketing efforts are being delayed until state guidelines for compost are finalized by the Florida Department of Environmental Regulation.

TABLE 4-3. MSW Composting Facilities in Operation in the U.S. as of 1988.

Location	Capacity (tonnes/day)	Years Established	Type of System	Material Added	Markets
Fillmore Co., Minnesota	13 to 18	1987	Windrow	--	None
Portage, Wisconsin	27	1986	In-vessel/drum	Sewage sludge	None
St. Cloud, Minnesota	45	1988	In-vessel/drum	Sewage sludge	None
Sumter Co., Florida	59 to 64	1988	Windrow	--	None
Wilmington, Delaware	900	1984	In-vessel/silo	Sewage sludge	None

* This facility was designed to process about 900 tonnes/day of MSW to recover RDF, glass and metals. An organic residue is mixed with sludge and composted in an in-vessel system.

Other Operational Facilities

Very little detailed information is available on the quantity or quality of the finished compost produced at the other three operational facilities. Moreover, their output of compost product has not been large enough to permit a long-term definition of the market for their respective products. The insufficient and sporadic production are explained by the fact that the facilities are in the testing and permitting stages.

4.2.3.2 Future Potential

The potential for implementing MSW composting facilities in North America appears to be bright. Composting is a particularly important alternative because it can easily be integrated with other material-recycling schemes and even with incineration. In addition, the possibility of using the refuse as a bulking agent for composting sewage sludge increases the potential considerably.

Before composting's bright future can be attained, a few obstacles must be removed. Among these obstacles is the present unavailability of MSW compost product in quantities sufficiently large to permit market evaluation and development. Another and serious obstacle is the relatively poor quality of the product to date. And lastly, reliability of the mechanical equipment must be improved.

4.2.3.3 Summary

The combination of high disposal fees, landfill shortages, and regulatory measures prohibiting the disposal of unprocessed MSW have increased the viability of composting as an option to manage MSW.

As of mid-1989, there are five full-scale MSW composting facilities in the U.S. Four of the facilities are relatively small and began operation after 1986. Only two of the plants (St. Cloud and Wilmington) were built by established vendors. With the exception of the processing plant in Wilmington, the other facilities process the entire waste stream. In general, limited information is available on the quantity of compost that is produced in each facility. Furthermore, the results of tests on the quality of the finished product are not readily available. It is apparent that these facilities have not been able to market the compost.

Since the majority of vendors have not built any MSW composting systems in the U.S., the following observations are based on the authors' experience. System vendors can be divided into those that *offer* equipment as well as operation and maintenance of the facility, and those that only offer equipment as well as operation and maintenance of the facility, and those hat only offer equipment. Some of the vendors such as Buhler-Miag and Dano have built several composting plants throughout the world. However, little information is available on the performance of the plants and the marketability of the compost.

Composting in other countries has been practiced for several years. Composting of MSW has been carried out in European countries at different rates. France, Germany, Italy, and Switzerland have been composting MSW with mixed success. Regulations controlling the use of MSW compost are such that the material cannot be beneficially used, particularly when the compost is made from mixed MSW. Thus, the current trend is to institute source separation and only compost the organic fraction. The largest fraction of the compost produced in Europe is used in large-scale agriculture (mushroom, farming, and viticulture).

4.2.4 Co-Composting

Co-composting is discussed at some length in Section 2, "Generic Composting Description." However, at this point, a few additional comments are mentioned, particularly with regard to the use of MSW as a bulking agent:

- Undesirable effects due to the shortcomings of raw refuse can be satisfactorily reduced Or even be avoided through a combination of: careful pre-processing, avoidance of high moisture content, and application of suitable mixing and aeration procedures.
- Regarding the relative economics of using wood chips as a bulking agent and those of using processed MSW, the appreciable monetary credits that would accrue from the use of MSW should be taken into account.
- Not to be overlooked is the possible sale of the co-compost product, and the utility of the product in soil reclamation and agriculture.

On the basis of this cursory comparison, one might conclude that in the future, the substitution of processed refuse for wood chips could be economically justified [6].

4.2.4.1 Co-Composting Facilities

As of early 1989, only three of the existing operational MSW composting facilities were practising co-composting: Wilmington, Delaware, St. Cloud, Minnesota and Portage, Wisconsin. Eleven MSW/sludge co-composting facilities were in the consideration and design stages. In addition, four facilities for co-composting sludge and yard wastes were in the consideration and design stages.

Although co-composting is being done at the Wilmington plant, only a fraction of the MSW is involved. The greater portion of the MSW is processed into refuse-derived fuel. The highly organic residue from the RDF processing is composted with sludge. However, all of the organic fraction of the MSW is co-composted at the Portage, Wisconsin, plant.

4.2.5 Yard and Garden Debris

Although the composting of yard and garden debris and similar residues is a practice of long-standing, it was not until this decade that it attained its present prominence. This prominence is attested by the impressive number of active yard waste and leaf composting facilities throughout the U.S. Moreover, there are ample reasons for expecting that within a few years, many additional facilities will be in operation.

The following four factors are especially responsible for the popularity: 1) The waste is easily composted. 2) The required technology is minimal. 3) Thus far, regulatory requirements are not demanding. 4) Recovery and utilization of yard waste are simple, yet highly cost-effective means of diverting the waste from disposal facilities.

Quantities of yard waste vary from region to region. The size of the contribution of the waste to a community's waste stream is not insignificant. Results obtained in waste characterization studies indicate that yard waste may comprise from 5% to 30% (by weight) of the municipal solid waste stream. The size of the contribution is a function of season and geographic area. Typically, the output of grass and yard waste is greatest from late spring until mid-autumn. On the other hand, most (about 70%) of the annual output of leaves is collected in the autumn. This can be a burden on the collection and disposal system. It should be noted that although grass and leaves are both constituents of yard waste, they often are handled separately.

The relative ease with which yard waste can be diverted from the landfill has prompted hundreds of municipalities to establish yard waste utilization programs. The movement is encouraged by legislative measures, some of which ban the disposal of yard waste in landfills. For example, in 1988, the State of New Jersey banned the disposal of leaves in landfills. Minnesota, Wisconsin, and Illinois have passed similar legislation.

Table 4-4 lists current and projected North American municipal yard and garden composting facilities.

4.2.5.1 Collection Strategies

To take full advantage of the basically organic nature of yard waste, it should be collected in a manner such that it remains free of objectionable contaminants. The establishment of drop-off sites and the institution of curbside collection are two effective strategies for avoiding such contamination.

Use of a drop-off site is the simplest and least expensive means of collecting yard debris. The drop-off site approach involves the placement of large containers in which the general public can deposit its yard waste in one or more strategic locations. The approach has an important drawback in that it relies upon the public to segregate the material as well as to transport it to the drop-off site. Thus far, experience with the approach has been characterized by a relatively low level of participation.

Several methods are available for curbside collection of yard debris. With all methods, the first and principal step required of the individual resident is that he or she segregate the yard waste and move it to a designated collection point. With one collection option, the waste is simply piled by the curb to await collection. The collection can be done either manually or mechanically. Another option calls for the resident to store the yard waste in a container for later collection. The container may be a can, box, or bag. The type of bag (i.e., plastic, paper, or biodegradable plastic) used by the resident exerts an impact on the remainder of the processing steps.

The collection of leaves from deciduous trees is a task of monumental proportions in some parts of the country. Because of the large quantities involved, collection and processing systems are established specifically for leaves. One such system consists of the use of vacuum trucks, although the cost these systems can be high (i.e., more than $ 88/tonne).

4.2.5.2 Compost Systems for Leaves

A very simple system for composting leaves is simply to stack them and then allow sufficient time for decomposition to take place. The retention time with such an approach may be as long as 18 months or more. The occasional emission of objectionable odours is inevitable during the first few months. This approach may be adequate where sufficient land is available. In situations in which unpleasant odours would not be tolerated, a more sophisticated approach may be required. This would involve processing the leaves using either the turned windrow or static pile technology. In essence, use of the both systems involves stacking the leaves in piles or windrows. With the turned windrow system, aeration is done by periodically turning the material. With the static pile, aeration is done by means of blowers. Moisture content and other parameters are suitably controlled. If either of the two systems is properly applied, the required detention time is a matter of weeks. The process can be expedited by adding a source of nitrogen. The two technologies are described in more detail in Section 2 and in the following subsection.

TABLE 4-4. Examples of Communities in Canada Composting Yard and Garden Waste.

Durham, Ontario
Essex-Windsor, Ontario
Guelph, Ontario
Metro-Toronto, Ontario
City of Toronto, Ontario
Ottawa, Ontario
Peel Region, Ontario
Peterborough, Ontario - Planning Stage
Waterloo, Ontario

Riley, Alberta

Halifax, N.S. - Planning Stage

Cap Rouge, Quebec
Urban Community of Montreal, Quebec - Planning Stage
Urban Community of Quebec City, Quebec - Planning Stage
Region of Quebec (City), Quebec
Ile d'Orleans, Quebec - Planning Stage
Verdun, Quebec
Kirkland, Quebec
Sherbrooke, Quebec - Planning Stage

Communities in U.S. Composting Yard and Garden Waste

Brookhaven, N.Y.
Davis, CA
Mecklenburg County, NC
Midland, Mich.
Milwaukee, Wisc.
Modesto, CA
Montclair, NJ
Palo Alto, CA
San Jose, CA
Scarsdale, N.Y.
Tenafly, NS
Urbana, Il
Wellesley, NJ
West Caldwell, NJ
Westfield, NJ

4.2.5.3 Compost Systems for Yard Wastes

Composting mixed yard waste is a complex undertaking. Consequently, it is unfortunate that some communities choose to follow a very low-technology approach. With such an approach, the material merely is stacked in piles *as* high as 3 to 6 m, and are allowed to remain undisturbed for period as long as 18 months or even longer. Almost inevitably this minimal approach leads to the development of nuisances, and during the dry season may result in a fire hazard.

In the paragraphs that follow are described compost systems that are appropriate for yard waste. Although the systems were described generically in Section 2, they are again described in this section, but in terms more specific to yard waste.

Turned Windrow and Static Pile

The turned windrow and the static pile are the systems most commonly used for composting yard debris. Aeration is accomplished by mechanical turning, by forced aeration, or by a combination of the two. Experience with the use of static pile system for composting yard waste has not been favourable. When used for composting yard waste, the static pile system can lead to an excessive drying and cooling of the composting mass, especially when tree trimmings and dried vegetation (leaves, snow) constitute a large fraction of the waste material. Ultimately, the excessive drying and cooling are due to the very porous nature of the wastes. The extensive porosity permits relatively unimpeded movement of air and diminishes the moisture retention capacity of the windrowed mass.

Equipment

It is essential to the success of a yard waste compost undertaking that a shredder or grinder be available that has the capacity to process the input intended for it. Despite the fact that this requirement seems to be obvious, lack of a shredder (or possession of an inadequate shredder) has been and is one of the more frequently encountered problems in yard debris compost projects.

To have an adequate capacity, the shredder must be able to size reduce fairly large branches and brush, as well as twigs, tree prunings, and other woody material to a particle size small enough to permit easy manipulation and to promote biological breakdown. In addition, the shredder should be sufficiently rugged to contend with occasional foreign objects such as rocks, bricks, and pieces of metal. If the shredder is inadequate, branches and other woody debris can accumulate at the site. This accumulation eventually can reach unmanageable proportions, become unsightly, and may even become a serious fire hazard.

With small operations, turning *can* be done satisfactorily with the use of a front-end loader or a bulldozer equipped with a standard blade. A mechanical turner specifically designed for the task would be necessary for large operations [7].

Moisture Content

The importance of maintaining the moisture content of the composting mass at a satisfactory level is often overlooked, usually because the water source is either inconveniently accessible or absent entirely. Even though extending a water line to the composting site may be costly, effective composting is impossible without water. A possible, but doubtfully acceptable, solution that might be tried if sufficient space is available, is to allow the piles to remain undisturbed until the rainy season comes. At that time, the compost program could be begun.

Product

The compost product is an excellent soil amendment and partial source of fertilizer elements, providing the yard waste had been maintained free of objectionable contaminants. After subjection to suitable screening, the product could be used for all landscaping activities.

4.2.5.4 Summary

The popularity of yard debris composting has increased substantially during the last few years. The main reasons for the popularity are: 1) the high costs of landfilling; and 2) the simplicity of composting. The number of composting facilities has grown from just a few to literally hundreds. This growth can also be attributed to legislative measures which prohibit the disposal of yard debris in landfills.

Processes generally involve size reduction and screening. The system most commonly used for composting yard debris is the open windrow. Both turned and static pile systems are used. Unfortunately, despite the fact that size reduction, aeration, and moisture control are essential to proper composting, a number of projects ignore these requirements. This has led to long composting times, the generation of nuisances, and even spontaneous combustion of the material during the dry summer months.

4.2.6 General Summary and Conclusions

At present in North America, composting seems to have a good position as a method of waste management. The number of projects for composting sewage sludge has grown substantially since the 1970s. Despite the occurrence of some potentially serious problems in recent years regarding heavy metal and toxic organic compound contaminants, the favourable trend probably will continue for the next few years.

Composting yard waste has certainly become very popular, as is evidenced by the tremendous increase in number of undertakings involving the composting of leaves and yard waste in general. A major drawback is the prevalence of the tendency to oversimplify. This tendency begins with design and continues through operation. Often, the tendency develops to a point at which management becomes non-existent. The oversimplification all too often is responsible for the generation of nuisances, fires, and production of a low quality compost. Nevertheless, the composting of yard debris will continue to be used as a means of diverting wastes from the landfill. This is particularly true in Ontario where a high level of government funding support and public enthusiasm prevails.

The composting of MSW will also continue to grow in the U.S., but probably not at a rate equal to that of yard debris. Major difficulties facing MSW composting include: 1) lack of basic design data; 2) absence of standards for the finished product; 3) insufficient experience on the part of most designers, vendors, and clients; and 4) overly optimistic expectations regarding markets and uses for the compost product [4,7,8].

Currently composting seems to have considerable public support and a good position as a waste management alternative. At present, there are hundreds of composting facilities throughout the world. The largest number of plants seems to be concentrated in the U.S. Similarly, there are several vendors offering various designs for treating organic residues through composting. It is extremely difficult to conduct a critical evaluation of each of these facilities by merely relying on information in the open literature. It is possible, however, to indicate some general advantages and disadvantages based on both the literature and the authors' observations.

Municipal Solid Waste

As of mid-1989, there were five MSW composting plants in the U.S. Only two of the plants were built by established vendors, i.e., Fairfield and Eweson. Unfortunately, the facility using the Fairfield unit only composts a fraction of the waste stream (rejects from RDF production). The Eweson plant, in St. Cloud, Minnesota, seems to be working adequately, although limited information is available on the quality of finished product.

Two of the other facilities (in Fillmore County, Minnesota and Sumter County, Florida) were designed specifically to meet the needs of the locale. Both designs incorporate manual separation. The Fillmore plant uses handpicking before size reduction. The Sumter plant uses manual separation after flailing. The facility in Portage does not rely on any type of separation prior to composting. These plants are all characterized by a relatively low throughput. The plants seem to still need to pay attention to the quality of the finished product. All facilities are making a concerted effort to evaluate and acquire equipment to process the finished compost. Types of equipment that have been evaluated include size reduction, screening, and air classification.

As of mid-1989, none of the facilities were selling their compost. Their inability to sell the compost was due to a combination of quality and absence of regulations applicable to compost from MSW.

Sludge

Sludge composting has grown substantially during the past few years. Currently windrow composting seems to be the most popular alterative. In-vessel composting is expected to increase in popularity. This is attributed to land requirements and containment of odors.

Most of the plants using windrows are operating satisfactorily. Most of them use some type of wood waste as a bulking agent. However, the price of the bulking agent is forcing some facilities to seek other materials. The main problem facing some of these plants deals with odor control. Some plants have had to completely enclose the composting areas.

There are several designs of in-vessel systems. They vary in shape and in orientation. Most of the plants seem to be meeting the U.S. EPA's time-temperature requirement. The majority use sawdust as a bulking agent. Several of the facilities initially had difficulties in marketing the compost. Some market their own product whereas others use a broker.

The major problem areas experienced by in-vessel systems are materials handling and odor control. The experience gained with the existing systems will be invaluable in the design, construction, and operation of future in-vessel systems.

Yard and Garden Debris

Thus far, most yard debris composting programs have not been designed and implemented by vendors. The majority of the processes are relatively simple. They typically involve size reduction by means of "tub" grinders. Yard debris composting projects have been largely encouraged by bans on the disposal of the wastes on landfills.

4.3 References

[1] "Composting Saves Landfill Space," World Wastes, 28(12):29-31 (1985).

[2] Goldstein, N., "Steady Growth for Sludge Composting," BioCycle, 29(10):27-36 (November-December 1988).

[3] Savage, GM., and L.F. Diaz, "Key Issues Concerning Waste Processing Design," Proceedings of the 1986 ASME National Waste Processing Conference Denver, Colorado, June 1986.

[4] Diaz, L.F., G.M. Savage, and C.G. Golueke, "Production of Refuse-Derived Fuel from Municipal Solid Waste," presented at the 79th Air Pollution Control Association Annual Meeting, Minneapolis, Minnesota, June 1986.

[5] Personal communication with Mike Olson, U.S. Waste Recovery, May 1989.

[6] Savage, G.M. and C.G. Golueke, "Major Cost Elements in Co-Composting, BioCycle 27(1):33-35 (January 1986).

[7] Savage, G.M. et al., Engineering Design Manual for Solid Waste Reduction Equipment, Report by Cal Recovery Systems, Inc. under U.S. EPA Contract No. 68-03-2972, 1982.

[8] Diaz, L.F., G.M. Savage, and C.G. Golueke Resource Recovery from Municipal Solid Waste, Vol. I, "Primary Processing" CRC Press, Inc., Boca Raton, Florida, 1982.

5.0 EVALUATION OF REPRESENTATIVE INTERNATIONAL FACILITIES

5.1 Introduction

Many of the same problems in waste management are being faced by nations worldwide: unavailability or unsuitability of land for landfills, increasing quantities of waste and poor acceptance of waste disposal facilities by the people. Numerous options to landfilling of wastes are being considered and implemented. Composting of organic wastes is among these options.

Although it is true that composting is an almost worldwide agricultural practice of long standing, it only began to be considered as an approach to waste management in the second half of the twentieth century. Since organic wastes typically constitute a large portion of the waste stream, treatment of these wastes can substantially reduce reliance on landfilling. In industrialized countries, composting has gained acceptance principally because it constitutes a means of waste disposal. In developing countries, the value of compost as a means of reclaiming the organic matter in waste is also an important factor. Restoring organic content of soil is essential to soil fertility, and thus to the production of dwindling food supplies in these countries.

The status of composting in North America *was* discussed in Section 4. The status internationally is approached in this section by discussing the current situation in some representative areas: Federal Public of Germany, France, Italy, Japan, South America, Soviet Union, Switzerland and the United Kingdom.

All costs in this section are in Canadian dollars.

5.2 Federal Republic of Germany

The Federal Republic of Germany faces many of the same waste management problems that are being faced by other countries: increasing quantities of waste requiring disposal or treatment; scarcity of areas suitable for new landfills; and poor acceptance of waste disposal facilities. An integrated approach to waste management has been selected in the Federal Republic of Germany as the most appropriate approach to waste management.

Approximately 30 million tonnes of waste were generated in Germany in 1980. At that time, the three disposal methods used were landfilling, incineration and composting [1]. About 1 million tonnes of waste were composted in 17 composting facilities. Processing facilities for the treatment of wood waste, bark and sludge were put into operation.

The quantity of sludge generated in 1980 was on the order of 40 million m^3 at 5% total solids. At that time, 40% of the sludge was used in agriculture, 40% disposed in landfills and 10% burned [1]. About 40 plants were composting sewage sludge [2].

The estimated amount of compost produced in 1983 is presented in Table 5-1. The data show that more than 700,000 tonnes of compost were produced. At that time, difficulties were experienced in marketing the composts, in particular those made from MSW and bark. These difficulties were attributed to excessive supply and poor quality [3].

Due to the high concentrations of heavy metals, as well as glass and plastics, the composting of MSW is expected to decline [2]. The trend in Germany now is towards the separate collection of organic and inorganic items [2,4].

TABLE 5-1. Estimated Amount of Compost Produced in Germany in 1983 [3].

Feedstock	Quantity (tonnes)
MSW and Sewage Sludge	220,000
Sewage Sludge	55,000
Leaves	100,000
Bark	200,000
Rumen Contents	40,000
Other Wastes	100,000
TOTAL	715,000

Separate collection of organic and inorganic items is not new to Germany. As early as 1903, an ordinance was passed in Hamburg which stipulated that each household have three waste storage receptacles: one for food wastes; a second for rubbish (paper, glass, pottery, etc.); and a third for ash, sweepings and dirt [5]. Research is currently being conducted in Germany on the effect of separate collection on the quality of the compost product. A demonstration study in the Mainz-Drais communities developed modelling systems to show the relation between various separate storage methods at the residence and associated methods of collection on the compost process feedstock. The modelling included the effect of composting method on important environmental and health parameters as well as on quality of product. Approximately 2,500 inhabitants were involved. With respect to product quality, results showed that heavy metal concentrations were substantially reduced through separate collection [5].

Systems for source separated collection of recyclable materials are continuing to be implemented in Germany. Currently, approximately 5% of residential waste is collected on a segregated basis and reprocessed, but it is expected that these quantities will increase to 30% to 45% [6].

Separate collection of the vegetables, fruit and yard waste (VFY) has been tried in about 80 communities at the pilot level. In the process, the VFY wastes are collected and taken to a composting facility. Results of pilot tests have demonstrated through separated collection of FVY, the concentrations of heavy metals in the compost can be reduced substantially. Demonstration projects concerned with the composting of vegetable-fruit-yard waste combinations are in progress in a number of cities including Heidelberg, Witzenhausen and Hamburg-Harburg [2].

Programs have also been implemented to collect decomposable materials in a container separate from other waste materials. This type of system (called 'Biodrum') is considered the best method for outlying areas. As shown in Table 5-2, the quantities of vegetable debris and biowaste produced in outlying areas is much greater than those produced in high density areas. Currently, approximately 350,000 German citizens are participating in this type of program. Plans are to eventually involve about 3 million of the population [6].

TABLE 5-2. Potential Amounts of Vegetable Debris and Biowaste Collected in Germany (kg/inhabitant/yr)[6].

Population Segment	Population Density	Vegetable Debris	Biowaste
City	2,000/km^2	20	50
High Density	1,000/km^2	25	70
Middle Density	500/km^2	30	90
Rural	150/km^2	35	160

5.3 France

Composting of organic residues, in particular MSW, has been practised in France for a number of years. It has been estimated that 95 processing facilities treat about 1.3 million tonnes of MSW a year. These facilities produce about 650,000 tonnes of compost [7-9].

There are about 8,000 municipal wastewater treatment facilities in France. These plants generate on the order of 600,000 tonnes of sewage sludge per year. Based on information collected in 1988, the sludge is treated or disposed in the following manner:

Landfilling	40% to 45%
Direct land application	40% to 45%
Incineration	5% to 10%
Composting and thermal drying	5%

Based on these data, it is apparent that landfilling and land application are the most popular waste management alternatives. The popularity is primarily due to economic reasons.

Currently there are five sewage sludge composting plants in France. Three plants use an in-vessel system, one windrow turning, and the other one static pile. It is expected that the number of sludge composting facilities will increase because of the constraints imposed upon landfilling and land application.

The agency responsible for dealing with wastes in France is the Agence Nationale pour la Recuperation et l'Elimination des Dechets (National Agency for Waste Recovery and Disposal), popularly known as ANRED. ANRED has been actively promoting the development of land application [7].

Furthermore, the Agency, long ago, recognized the importance of MSW composting in France and set up a special team to evaluate the status of the process. The team conducted a series of investigations to assess the impact of mechanical processing, in particular size reduction, on the quality of the compost, conditions for optimum separation and other aspects of waste processing [8]. Typical mechanical processing systems include: size reduction: density and ballistic separation; air classification; and electromagnetic separation. Manual separation sometimes is included in the processing schemes.

Composting methods used in France are classified as rapid fermentation and open air natural fermentation [9,10,11]. Rapid fermentation generally involves mechanical separation of organic matter and then the use of either vertical or horizontal reactors. Environmental conditions in the reactors are controlled. Aeration is accomplished through mixing, tumbling or forced injection. Some of the systems used include: OTVD, Sogea, Siloda and Triga [9,12].

Open air natural fermentation is conducted by stacking the material in windrows. Aeration is provided by periodically turning the piles. Windrow turners may or may not include size reduction [9].

Maturation follows the active composting state. The windrows are aerated at regular intervals (usually bi-monthly). The maturation period depends upon the intended use of the compost and may last up to eight weeks.

The French government has promoted composting through publicity and the provision of subsidiaries and low interest loans to municipalities [11,13]. An in-vessel composting facility capable of treating about 120 tonnes of residential waste per day cost about $ 1.2 million in the early 1980s. The operating costs were on the order of $ 10 per input tonne. Income from the sale of the compost was reported as $26,000 per year or about $2.60 per tonne of compost [13].

Approximately 650,000 tonnes of compost were produced in France in 1984. About 555,000 tonnes or 85% of the material was sold [9]. The approximate distribution of the end users is presented in Table 5-3. The data in the table show that mushroom growing, large-scale fanning and viticulture account for nearly 90% of the total output. The average selling price is about $ 3.76 per tonne at the facility [9].

TABLE 5-3. Uses of Compost From MSW in France [9].

Use	Weight (%)
Mushroom Growing	36.6
Large-Scale Farming	28.7
Viticulture	24.3
Tree Farming, Horticulture Nurseries	4.3
Arboriculture	4.0
Miscellaneous (Retail)	2.1

5.4 Italy

The estimated quantities of wastes generated in Italy are presented in Table 5-4. The data in the table show that about 173 million tonnes of wastes are generated each year. About 18 million tonnes or nearly 10% of the wastes are generated in urban cities each year [14].

The strategies followed for managing urban wastes include energy and material recovery, Composting is one of the approaches adopted for stabilizing the organic matter in the wastes.

A summary of the status of composting facilities is given in Table 5-5. The information in the table show that there are 21 facilities currently in operation capable of treating about 3,300 tonnes of refuse per day. It is expected that 97 more facilities will be on line in the near future. The total daily capacity would be on the order of 20,100 tonnes/day. Eleven facilities incorporate sludge. The types of facilities include: circular reactors, rotating cylinders, primary cells, vertical reactors, rectangular reactors and windrows. All systems incorporate a rapid (accelerated) composting phase and a maturation phase. The most common maturation process is the windrow. Process duration ranges from two to 152 days. The average duration is 50 days.

In the areas where compost is used, demand is concentrated in the spring and fall seasons. This is primarily related to agricultural practices. The selling price for the compost varies from about $ 4.70/tonne to $ 40/tonne, with the most common being $18/tonne. Some facilities propose to sell the material in bags for about $ 59/tonne and densified and bagged for approximately $ 118/tonne.

5.5 Japan

The use of organic residues for composting and land reclamation attracted a considerable amount of attention in Japan in the mid-1950s. The interest declined after 1967 and reached a low in 1976. The energy crisis for the 1970s resulted in the development and construction of new facilities [5].

The use of mechanical systems for composting MSW in Japan began in 1955. The number of plants reached its peak of 29 in 1967. However, due to the increase in plastics and heavy metals in the waste as well as the availability of chemical fertilizers, the number of plants decreased sharply to about 7 in 1976. The energy crisis of the 1970s led to the development of mechanical refuse processing systems. Some of these systems involve simultaneous size reduction and classification [16]. In 1983, about 69% of the MSW was incinerated and less than 1% was composted. This corresponds directly to the first line of Table 5.6. The facilities composting MSW are located in small communities and subsequently are small in size. Composting was primarily practised in these communities through the collection of source separated organic residues [17].

It has been estimated that more than 1.8 million dry tonnes of organic residues currently are generated in Japan. The data in Table 5-6 show that presently there are over 2,132 composting plants in Japan. Most of the plants have been designed to process animal manures. In addition, there is a considerable amount of organic waste generated by industry. Some of this waste is composted. Unfortunately, the actual amounts are now known [15,18].

TABLE 5-4. Estimated Quantity of Wastes Generated in Italy (14].

Type	Quantity (tonnes/yr)
Urban	18,000,000
Industrial	50,000,000
Agricultural	100,000,000
Sewage Sludge	5,000,000*
TOTAL	173,000,000

* Municipal sludge at 20% total solids.

TABLE 5-5. Status of MSW Composting Facilities in Italy [14].

Status	Number	Quantities Treated (tonnes/day)
In Operation	21	3,300
Under Construction	16	3,600
Planned	81	13,200
TOTAL	118	20,100

TABLE 5-6. Estimated Number of Composting Facilities in Japan [15].

Residue	Number
MS W	22
Sewage Sludge	31
Night Soil*	9
Manure	> 2,000
Bark	70
Industrial	Unknown
TOTAL	> 2,132

* Untreated human excrement

The number of sewage sludge composing facilities increased from less than five in 1977 to 31 in 1989. The Association for the Utilization of Sewage Sludge was established in 1977. The Association is actively promoting the use of sewage sludge [9] It has been estimated that about 54% of the sludge is incinerated and only 9% is composted [13].

The most common types of composting systems are the in-vessel systems. These systems generally include either vertical or horizontal reactors. The reactors are equipped with units to provide forced aeration and mechanical agitation [20].

The most common problem associated with plant operation is the control of moisture content of the substrate. The most common methods to adjust the moisture content are by means of either recycling some of the finished product or adding a dry organic residue. Odour and odour control also are two important operating problems. Most of the facilities are equipped with odour control devices [20].

The average sale price for the finished product varies from $ 41 to $ 91 per wet tonne in bulk form. Bagged composts sold from $ 113 to S 175 per wet tonne.

Capital costs for composting facilities range from $ 14,000 to more than $ 1.4 million. The average operating costs fluctuate from $ 76 to $ 376 per wet tonne of compost. The major fraction of the operating costs are attributed to labour costs [15].

The constriction of most composting plants was carried out with government subsidies. The ratio of subsidy to capital cost ranges from 25% to 88% [15].

5.6 South America

In comparison with other areas, composting has not received much attention in South American countries. Most countries in the area still rely on land disposal as the primary means of waste management. One exception is Brazil.

The City of Sao Paolo, Brazil, for example, has two composting facilities that treat municipal solid wastes utilizing the Dano process. One plant has a minimal capacity of 210 tonnes/day, and the other a capacity of 420 tonnes/day. The City is in the process of increasing the capacity of one of the plants from about 150,000 tonnes/year to approximately 264,000 tonnes/year [21].

A 660 tonnes/day facility was built in 1986 in Brasilia, Brazil, to process mixed municipal solid waste. The recyclable materials are sorted from the compostables and rejects. The organic stream is added to the top of vertical concrete towers where it is processed for approximately six days. The material is then cured in windrows for an additional 30 to 60 days. The compost may then be screened or shredded, depending upon intended markets [22].

Recent efforts in improving the quality of the compost has developed a market in the producers of "organic fertilizers" in Brazil. In Sao Paolo, it is also expected that the compost will be used for sugar cane farming. The pricing policy for the compost is expected to be as follows: cured compost will sell for $ 5.30/tonne and the new upgraded product will sell for $ 11.80/tonne [21].

In Brazil, the compost is presently being sold for one-third the cost of commercial mineral fertilizers. The high demand for organic soil amendments is the result of poor soil conditions in the area [22].

5.7 Soviet Union

Despite the increasing awareness of problems associated with landfilling in its more densely populated regions, landfilling remains the usual method of municipal waste disposal in the Soviet Union. Although not to the same degree, the problems are of the same nature and origin as those in almost all industrialized countries. One such problem is that despite the vast land area of the Soviet Union (22.3 million km% there is a shortage of available area for siting landfills within a reasonable distance from the communities in which waste is generated. For example, waste from Moscow is currently transported 80 to 97 km for landfilling [23]. Undesirable impacts exerted on soil and water resources by leachate from landfills are beginning to be recognized and acknowledged.

The landfill situation, combined with both a hesitance to resort to incineration as an alternative as well *as* new developments in compost technology, are enhancing the prospects for composting in the USSR. Other factors are adding to the attractiveness of composting. One such factor is an almost insatiable demand for soil conditioners and fertilizers [24]. According to Pickard, use of fresh compost as a heating element *in* greenhouses and cold frames operated on state and communal farms accounts for a significant part of this demand. (Use for this purpose involves placing topsoil over 18 inches of fresh compost. The compost provides sufficient heat to extend the growing season by several weeks.) Yet another helpful factor is the relatively high fraction (33%) of food preparation wastes in the municipal waste stream. The composition of domestic refuse from the city of Minsk is indicated by die data in Table 5-7.

TABLE 5-7. Composition of MSW in the City of Minsk, Soviet Union 124]

Component	Average (%)
Paper	22.3
Food Wastes	38.0
Wood	1.2
Metal	3.8
Bone	1.7
Leather, Gum	2.0
Textile	2.9
Glass	6.0
Stones	3.0
Plastics	6.0
"Wastes"	12.0

Approximately eight mechanical composting facilities are in operation in the Soviet Union.

Sewage sludge and MSW are being co-composted at the Leningrad and Minsk plants. These plants are designed to process 200,000 and 88,000 tonnes of MSW/yr respectively. The mechanical composting operations in Leningrad and Minsk are typical of those in the Soviet Union [23].

The plant at Minsk produces 45,000 tonnes of finished compost/year. It has four rotating drums, each of which is 4 m in diameter and 35 m in length. The interior of each drum is equipped with baffles. Freshly collected refuse is brought to the plant and dumped into a receiving bin. The fresh refuse is then loaded without preprocessing into the drums by way of two independent lines. Size reduction occurs as a result of the tumbling in the drum. The material remains in the drums over a two day period, after which it is transferred to the "crushing screen shell", in which it is screened and separated into compostable and non-compostable fractions. The screened material is then windrowed and allowed to cure until there is a need for the finished product [23,24].

5.8 Switzerland

Composting of organic residues has been practised in Switzerland for several years. It has been estimated that more than 200,000 tonnes of waste were composted in 1975. However, the increases in quantities of waste generated and in the concentration of potentially toxic chemicals in the waste led to concern about excessively high concentrations of harmful substances in the compost [25].

The need for means of waste disposal led to the expansion of incinerator capacity. Despite the use of sophisticated air pollution control equipment, substantial concentrations of pollutants escaped to the atmosphere. In addition, reliable methods of ash disposal were lacking. It was concluded that environmental conservation rather than simply cost had to be the most important criterion for waste disposal. Consequently, composting was again considered a viable alternative, provided that low concentrations of toxic compounds in the finished product could be achieved [25].

In order to evaluate the sources of heavy metals in the waste stream, a series of tests were carried out in West Germany and in Switzerland. The results of the tests indicated that separation of compostable items could be based on established criteria. Furthermore, the results showed that compost produced from properly source separated organic matter would meet the desired specifications (i.e., good appearance and low level of contaminants) [26-29].

Currently, there are a number of relatively small composting facilities throughout Switzerland. The facilities have a capacity of 200 to 25,000 tonnes per year. The tipping fee has been reported to range from about $ 35 to $ 59 per tonne.

Most new facilities take into consideration the concerns regarding emissions, as well as strict standards regarding quality of the finished product [25].

5.9 United Kingdom

Approximately 20 million tonnes of municipal solid waste is generated in the United Kingdom each year. Of this, about 18 million tonnes (approximately 90%) are landfilled annually, and the rest is treated thermally. The major reason for the high percentage of waste going to landfill is the relatively low cost of landfilling compared to that of alternative disposal schemes [30).

The first full-scale refuse composting facility in England was established in 1947 [31]. A survey conducted in 1973 determined that 21 local authorities claimed some experience in composting. The survey also found that there were 11 operating facilities. However, all of the facilities were closed by the end of 1987. The primary reason for the closures was the lack of markets for products.

Although much research work has been carried out on various aspects of composting, no full-scale composting facilities are operating in the United Kingdom at this time [31-34]. Some in-vessel systems currently are being used as **a** means to accomplish volume reduction prior to landfilling [6].

5.10 References

[1] Lutz, W., "International Perspectives on Composting", BioCycle, 25(2):22-25 (March 1984).

[2] Stegmann, R. and U. Krogmann, "Composting of the Organic Fraction of Municipal Solid Wastes Separated 'Through Selected Collection", presented at the International Symposium on Compost Production and Use, S. Michele All'Adige (Trento), Italy, June 1989.

[3] Mach, R., "Processing 700,000 Tons Per Year in Germany", BioCycle 24(1):37-38 (January/February 1983).

[4] Salimando, J., "Glimpses of German Waste Solutions", Waste Age 20(6):112-116 (June 1989).

[5] Funke, U. and G. Muller, Getrennte Werstofferfassung end Biokompostierung, EF-VERLAG fur Energie und Unwelttechnik GmbH, 202 pp., 1988.

[6] Scheffold, Karlheinz, "Source Separation and Collection in Germany", Biocycle, 30(7):22-29 (July 1989).

[7] Merillot, TM., "Recycling Organic Municipal Wastes in France", BioCycle, 30(7):30-31 (July 1989).

[8] Begnaud, B. and N. Noyon, 'Processing Household Refuse by Separation and Composting", Conclusions of the ANRED Program, 1984-1986.

[9] De Lauzanne, R., "Methodologies and Technologies in Compost Production: The French Experience" presented at the International Symposium on Compost Production and Use, S. Michele All'Adige (Trento), Italy, June 1989.

[10] Mousty, P.A. and M. Reneaume, "Household Refuse Composting in France", BioCycle, 25(2):26-29 (March 1984).

[11] "French Farmers Favour Cordon Bleau Compost", Surveyor (September 24, 1981).

[12] Lavasseur, J.P., "Household Refuse Recycling in France", BioCycle, 29(6):32-33 (July 1988).

[13] Shimell, P., "Refuse Derived Compost Boosts Vineyard Yields", World Wastes, 26(11):89 (November 1983).

[14] Zonzi, G. and G. Urbian, "Reality and Guidelines of the Italian Situation", presented at the International Symposium on Compost Production and Use, S. Michele All'Adige (Trento), Italy, June 1989.

[15] Kubota, H. and K. Nakasaki, "State of the Art of Compost Systems: The Current Situation and Future Outlook in Japan", presented at the International Symposium on Compost Production and Use, S. Michele All'Adige (Trento), Italy, June 1989.

[16] "Ebara Municipal Solid Waste Composting System", Ebara Environmental Corporation, Greensburg, Pennsylvania, March 1989.

[17] Chanyasak, V. and H. Kubota, "Source Separation of Garbage for Composting", BioCycle, 24(2):56-58 (March-April 1983).

[18] Kubota, H., S. Matsuda and M. Sasaki, "Composting Has Promising Future in Japan", BioCycle, 25(3):28-31 (April 1984).

[19] Golueke, C.G., "Wastewater and Sludge Management in Japan", BioCycle, 24(2):44-47 (March-April 1983).

[20] Terasawa, M., M. Hirai and H. Kubota, "Soil Deodorization Systems", BioCycle, 27(6):28-32 (July 1986).

[21] Guaraldo, CR., "MSW Composting Facilities in Sao Paolo, Brazil", BioCycle, 30(6):82-84(June 1989).

[22] Stucki, H. and F. Mitchell, "Processing Wastes in Brasilia", BioCycle, 30(7):60-61 (July 1989).

[23] Peterson, C. and A. Perlmutter, "Composting in the Soviet Union", BioCycle, 30(7):74-75 (July 1989).

[24] Pickard, R.O., personal communication to the Coordinator, Transportation and Works Policy Committee, Regional Municipality, Ottawa-Carleton, Canada (September 21, 1988).

[25] Mayer, M., H. Hofer and U. Marie, "Trends in Yard Waste Composting", BioCycle, 29(6):60-62 (July 1988).

[26] Obrist, Walter, "Material Balance of the Composting Process", BioCycle, 28(2):32-33 (February 1987).

[27] Personal communication with representative from Switzerland, P. Selldorf, Consorzio per l'Eliminazione del Rifiuti del Luganese (June 1989).

[28] Baccini, P. and P.H. Brunner, "Sortierung in der Abfallwirtschaft: Wie gross ist ihr Beitrag zu einem ressourcenschonenden and umweltvertraglichen Stoffhaushalt?" Gas, Wasser, Abwasser, 68(11):617-622 (1988).

[29] Obrist, W. and P. Baccini, "Auswahlkriterian fur Kompostierbare Abfalle", Wasser,Energie. Luft - Eau, Energie, Air, 78(Heft 11/12):290-294 (1986).

[30] Bardos, R.P., "The Potential of Biological Processes in Municipal Solid Waste Management Systems", presented at the Second Combustion Workshop, Birmingham, England, December 1988.

[31] New, R. and R. Papworth, Glass Contaminant Removal from Refuse Derived Compost Interim Report, LR 692 (MR) M, Warren Spring Laboratory, Stevenage, England.

[32] Bardos, R.P. and J.M. Lopez-Real, "The Composting Process: Susceptible Feedstocks, Temperature, Microbiology, Sanitisation, and Decomposition", presented at the EC Workshop in Waste Management, Monastery of Neresheim, Germany, September 1988.

[33] Bardos, R.P., "Composting Studies Using Separated Fractions of Urban Waste from the Byker Reclamation Plant, New Castle, U.K.", for presentation at the International Symposium on Compost Recycling of Wastes, Athens, Greece, October 1989.

[34] Stentiford, E.I., T.J. Pereira-Neta, P.L. Taylor, D.D. Mara, J.M. Lopez-Real and E. Witter,"Sanitisation Potential of Composting for Sewage Sludge and Refuse in a Static Pile System", pp. 269-275, *In* Advances in Water Engineering, T.H.Y. Tebbutt, Ed., Elsevier Appl. Science Publ., 1985.

[35] Personal communication with Brian Jones, July 1989.

6.0 DOCUMENTATION OF POLICIES, REGULATIONS, STANDARDS AND/OR GUIDELINES

Although composting has been utilized as a means of waste management since the early 1940s, most policies and regulations geared specifically at the compost facility, process, and market either have recently been developed or are still in the developmental stages.

In Canada, only the provinces of Quebec and Ontario have developed policies specifically *for* composting operations. Other provinces either apply existing regulations for land application of sewage sludge, examine projects on a case-by-case basis, or have no applicable regulations (see Table 6-1).

In the United States, the Environmental Protection Agency has been active in developing regulations pertaining to the treatment and distribution of sewage sludge products (including Compost). Regulations related to the composting of municipal solid waste and of yard debris generally have been the responsibility of state and municipal governments.

Internationally, the Commission of the European Communities has taken the lead in developing policies and guidelines for compost operations in Europe. Individual countries, some of whom are members of the CEC, that also have developed compost guidelines include Austria, The Netherlands, Belgium, Switzerland, the Federal Republic of Germany, Spain, and France.

A discussion of some of the policies and regulations that have been, or are being, developed for composting operations is provided in the remainder of Section 6. The discussion is divided into the following areas: compost quality and standards; facility siting and approvals; health and safety requirements; and hazardous waste handling, storage, and disposal.

6.1 Compost Quality and Standards/End Use Regulation

Compost quality is a function of the physical, chemical, and biological characteristics of the product. Some of the physical characteristics desired of a product are a dark colour, uniform particle size, a pleasant earthy odour, and absence of contaminants. The compost should be free of clumps and should not contain identifiable contaminants such as glass shards and pieces of metal and plastics.

Regulations regarding the use of compost from solid waste and sewage sludge have primarily centred around the potential public health problem of introducing toxic compounds into the food chain. Heavy metals, PCBs, and other toxic materials are present in wastewater streams and in some solid wastes. Consequently, they can be present in the compost to be applied to the land or used as a growing medium in containers. Since some amounts of the toxic compounds are assimilated by plants, they can potentially be transmitted to animals and humans consuming the crops. Most compost standards, therefore, limit the concentrations of toxic materials in the compost product. Other standards that can be applied to compost products include particle size requirements, limits on the percent of foreign material present in the finished product, and degree of maturity.

TABLE 6-1. Canadian Policies, Regulations, Standards and/or Guidelines

Newfoundland	- None. - Waste Material Disposal Act (1973) covers land application of manure only.
Nova Scotia	- None. - Projects or proposals will be examined on a case-by-case basis.
Prince Edward Island	- None.
New Brunswick	- None. - Projects or proposals will be examined on a case-by-case basis.
Quebec	- The following are requirements for a solid waste composting plant: • at least 150 m from a floodplain and lands designated by a municipal government as residential, commercial or mixed residential/ commercial; • at least 150 m from any municipal park, golf course, alpine ski trail, recreation area, public beach, ecological reserves, parks, oceans, rivers, streams, ponds, swamps or sandbanks; • at least 300 m from any dwelling, educational institution, religious edifice, food processing establishment, campground, restaurant, hotel, holiday camp and health and social service establishments; • at least 300 m from any lake; • have a sign identifying the facility and the operating permit posted; • only solid waste, non-contaminated biomedical waste which is solid at 20°C other than human anatomic waste, non-toxic residues solid at 20°C from pulp and paper plants and sawmills, non-toxic mud capable of being shovelled and a maximum of 100 m^3 of earth and sand impregnated with less than a mass of 5% hydrocarbons per period of four months and non-toxic mud that is not capable of being shovelled; • not burn any wastes; • composting residues and solid waste not accepted at the composting facility must be landfilled; and • ensure that wastewater meets storm sewer regulations.

TABLE 6-1 (Cont'd). Canadian Policies, Regulations, Standards and/or Guidelines.

Ontario	- Internal Interim Guidelines on Composting (1982) are used for approval purposes. - Exemption from Environmental Assessment Act if facility produces less than 200 tonnes/day of residual waste after composting.
Manitoba	- None.
Saskatchewan	- None.
Alberta	- None. - Proposed projects would be evaluated using existing regulations for land application of sewage sludge and water quality guidelines.
British Columbia	- None.
Northwest Territories	- None.
Yukon	- No information.
Environment Canada	- None.

Sewage sludge composts and, to a smaller degree, MSW composts can contain human coliform bacteria and other potentially harmful pathogens and fungi. Utilization of proper composting methods, especially maintenance of thermophilic temperature levels, has been demonstrated to be effective in destroying pathogens. Studies have shown that in windrow composting it is necessary to maintain a minimum temperature of 65°C for at least one week to produce a hygienically safe product [1]. Generally, in-vessel systems require less time.

Compost produced from yard debris may also contain toxic compounds such as insecticides and pesticides. This material may also be the source of weed seeds and plant pathogens [2].

In summary, both final product standards and operational regulations have been found to be necessary to control the quality and safety of the compost product. Ultimately, compost quality is a function of the composition of the feedstock and of the type and thoroughness of the separation process.

6.1.1 North America

In Canada, contacts with provincial governments indicated generally that no policies, regulations, standards, or guidelines were in effect regarding compost quality. The exceptions were Quebec who have guidelines and Ontario who utilize "internal" guidelines for approval purposes.

In the United States, the Environmental Protection Agency has been involved in developing regulations regarding sewage sludge treatment and disposal. Recently, proposed guidelines were developed regulating contaminant limits for compost and other sewage sludge products that are intended for distribution and marketing. The contaminant limits are based on annual sludge application rates (see Table 6-2) and include many pesticides and herbicides that presently are not regulated by individual States. The U.S. EPA also proposed a set of limits for sludge products intended for non-agricultural land (Table 6-3). The proposed limits do not apply to compost from MSW or yard debris. These limits may be revised. They are the most current as of writing.

A number of States in the U.S. have developed compost quality standards which regulate compost products intended for distribution. Compost standards from nine States are presented in Table 6-4 as examples of guidelines in the U.S. As shown in the table, all nine of the States regulate the concentrations of heavy metals in the compost, and most regulate PCB concentrations as well. Florida, in its draft regulations, has developed more stringent guidelines for compost products by setting standards for compost maturity, maximum particle size, and foreign material content.

As shown in the table, compost from sewage sludge is regulated more often than MSW or yard debris composts, primarily because large-scale facilities have been operational for a longer period of time, and also because of the relatively high levels of heavy metals and pathogens in raw sewage. The number of States that are developing regulations for MSW compost is increasing as more facilities are becoming operational. In many cases, the regulations for MSW compost have been adapted from those for sludge.

Yard debris compost is generally regulated less stringently than composts from sewage sludge or MSW, because the compost is considered to pose less of a potential environmental hazard. Of the States listed in Table 6-4, Massachusetts is the only one that includes yard debris compost in its contaminant testing requirement. Florida has a classification for compost generated from yard waste or manure, but compost generators are not required to subject their product to laboratory tests. It is assumed that the concentrations of heavy metals in yard debris compost will be within the limits listed in Table 6-4.

TABLE 6-2. U.S. EPA Distribution and Marketing Pollutant Limits for Sewage Sludge Products [3].

Whole Sludge Application Rate (Mg/ha)	1	3	5	10	15	20	25	30	35	40	45	50
	Maximum Sludge Concentration (mg/kg dry wt. basis)											
Aldrin/dieldrin	16	5.5	3.3	1.5	1.1	0.82	0.56	0.56	0.47	0.41	0.25	0.33
Arsenic	700	230	140	70	47	35	28	23	20	18	15	14
Benzo(a)pyrene	30	25	15	7.7	5.1	3.8	3.1	2.5	2.2	1.3	1.7	1.5
Cadmium	900	310	180	90	61	46	37	31	25	23	20	18
Chlordane	22.500	7.500	4.500	2.200	1.500	1.100	900	750	640	550	500	450
Chromium	25.500	5.300	5.500	2.700	1.770	1.330	1.060	580	750	650	590	530
Copper	2.300	770	450	230	150	110	92	77	55	57	51	45
DDT, DDE/DDD, total [a)]	48	15	9.2	4.5	3.1	2.3	1.8	1.5	1.3	1.2	1	0.22
Heptachlor	79	25	19	7.9	5.3	3.9	3.2	2.5	2.3	2.	1.3	1.5
Hexachlorobenzene	45	15	9.1	4.5	3.	2.3	1.8	1.15	1.3	1.14	1.01	0.31
Hexachlorobenzidene	41.200	14.000	8.200	4.100	2.700	2.100	1.500	1.400	1.200	1.000	910	320
Lead	5.000	2.100	1.300	500	400	310	250	210	180	150	140	130
Lindane	293.500	97.800	58.700	29.350	19.570	14.680	11.740	9.780	8.350	7.340	5.500	3.370
Mercury	1.900	660	400	199	133	99	80	65	57	50	44	40
Nickel	3.900	1.300	780	290	260	200	150	130	110	98	37	75
Polychlorinated biphenyls	49	49	30	15	10	7	6	5	4	4	3	3
Selenium	8.106	2.702	1.500	810	540	410	320	270	230	200	160	150
Toxaphene	117	39	23	12	7.5	5.8	4.7	3.9	3.3	2.9	2.5	2.3
Zinc	5.500	2.900	1.700	850	570	430	340	230	250	220	180	170

a) DDT - 2,2-bis(chlorophenyl)-1,1,1-trichloroethane
DDE - 1,1-bis(chlorophenyl)-2,2-dichloroethylene
DDD - 1,1-bis(chlorophenyl)-2,2-dichloroethane

TABLE 6-3. Proposed Pollutant Limits for Sewage Sludge Compost Applied to Non-Agricultural Land [3].

Pollutant	Maximum Concentration (mg/kg, dry wt. basis)
Aldrin/dieldrin	0.33
Arsenic	36
Benzo(a)pyrene	6.9
Cadmium	380
Chlordane	24
Chromium	3100
Copper	3300
DDT/DDE/DDD (total) [a)]	0.11
Dimethyl nitrosamine	1.4
Heptachlor	1.5
Hexachlorobenzene	2.8
Hexachlorobutadiene	6.8
Lead	1600
Lindane	92
Mercury	30
Molybdenum	230
Nickel	990
Polychlorinated biphenyls	0.11
Selenium	64
Toxaphene	0.97
Trichloroethylene	180
Zinc	8600

a) DDT - Bis 2,2-(chlorophenyl)-1,1,1-trichloroethane
DDE - Bis 1,1-(chlorophenyl)-2,2-dichloroethene
DDD - Bis 1,1-(chlorophenyl)-2,2-dichloroethane

TABLE 6-4. Compost Quality Standards for Various States in the U.S. (ppm).

State	CO	CO	CO	DE	FL	FL	FL	FL	IL	IL	MA	MA	MO	MN	NY	NY	PA
Feedstock:	SL	SL	SL	SL	YD/MAN	SL/MSW	SL/MSW	SL/MSW	SL	SL	SL/MSW YD	SL/MSW	SL		SL/MSW	SL	SL/MSW
Usage:	U	L5	L1	U	U a)	U	L2	L5	U	L4	U	L1	U	U	U	L1	L3
Mercury				5							10	10	5	5	10	10	10
Cadmium	25	70	125	12.5	15	15	100	>100	10	25	2	25	12.5	10	10	25	25
Molybdenum											10	10					
Nickel	250	650	1250	100	50	50	500	>500			200	700	100	100	200	200	200
Lead	1000	2500	5000	500	500	500	1500	>1500			300	1000	500	500	250	1000	1000
Chromium											1000	1000		1000	1000	1000	1000
Copper	625	1550	3125	500	150	450	3000	>3300			1000	1000	500	500	1000	1000	1000
Boron											300	300					
Zinc	1250	0325	6250	1250	900	500	10000	>10000			2500	2500	1250	1000	2500	2500	2500
PCB	5	10	10								2	10	5	1	1	10	3
Particle size (mm)					<25	<10	<25	<25							<10	<25	
Foreign material					<10%	<10%	<30%	<40%									
Maturity	Stable	Stable	Stable			Mature	Mature or semi	Can be fresh			Stable	Stable	Stable	Mature			
References	[11]	[11]	[11]	[10]	[7]	[7]	[7]	[7]	(9)	[9]	[5]	[5]	[5]	(2)	[4]	[4]	[8]

Usage: U = Unrestricted distribution.

L = Limited distribution:

1) Non-food chain crops; 2) Commercial, agricultural, Institutional or governmental agencies;

3) Public distribution; 4) Public distribution: non-leafy green crops

5) Landfill or land reclamation uses: 6) Sericulture or disturbed land.

a) Not subjected to testing: compost is assumed to meet limits for heavy metals.

A few U.S. States have developed a classification hierarchy in which compost products meeting the most stringent requirements are allowed the widest distribution, i.e., non-restricted use. Conversely, composts with higher levels of contaminants are restricted in use to non-food chain crops, or to use as landfill cover or in land reclamation projects. Table 6-4 presents the acceptable concentrations for the various applications for Florida, New York, Massachusetts, and Minnesota.

6.1.2 International

The Commission of the European Communities (CEC) has been actively involved in the development of specifications for different types of compost. In addition to the CEC, a number of countries have also developed guidelines for compost quality. A discussion of compost quality standards developed by the CEC, France, Austria, Switzerland, Spain and Japan are presented below.

6.1.2.1 Commission of the European Communities

The CEC's objective is to develop compost quality specifications that would be accepted throughout the member nations and would "guarantee users a specific product quality and properties which would remain standard over time and which would be tailored to the different ways in which compost is used" [12]. The CEC takes the position that in order to be marketed, compost must be accompanied by specifications relative to its origin, composition and degree of stabilization [1]. Compost specifications proposed by the CEC define the following physical and chemical parameters: particle size and organic matter, moisture content, inerts, mineral contents, initial and final C/N values, salinity, and pH.

Currently, CEC specifications are at variance with national legislation or current practice in some of its member nations including Belgium, France, Federal Republic of Germany, and The Netherlands. The United Kingdom does not currently have guidelines for limits on heavy metals and other contaminants in MSW compost, but has not accepted the limits proposed by the CEC. As of June 1989, Ireland, Italy, and Denmark were expected to approve the proposed specifications [12].

Particle Size, Organic Matter, Moisture and Inerts -- Four grades of compost product are proposed by the Commission of the European Communities. Table 6-5 presents the acceptable limns for particle size, biodegradable organic matter content, moisture content, and inerts (glass and plastic) for the four grades of MSW compost. Moisture content is an indication of progress in the composting process. A compost with a relatively low moisture content is also beneficial in that it avoids the unnecessary transportation of water, and it helps in sieving, storing or spreading operations. Agricultural use of compost requires a product substantially free of inert matter. In addition to meeting the maximum levels for glass and plastics presented in Table 6-5, ferrous metals should be practically absent, and non-ferrous metals only present a low level [1].

Nutrient Content -- Minimum levels for nitrogen, potassium, phosphate, calcium, and magnesium also are included in the specifications developed by the CEC. The CEC specifications are compared with actual average values from France in Table 6-6. The CEC also recommends that the initial and final C/N ratio for each compost product be specified. As an example, when the starting material has a C/N ratio in the range of 35 to 40 or slightly above, the final C/N ratio should be below 22 in order to achieve the degree of stabilization required. When wastes contain nitrogen-rich products, the final C/N values are expected to be proportionally lower, yet not below 11 to 12.

TABLE 6-5. CEC Requirements for MSW Compost Characteristics According to Grade of Product [1,12].

		Very Fine	Fine	Medium	Coarse
Sieve size (mm)		8	16	24	40
Maximum inerts (% dry wt)					
Glass --	Present	1	2	4	6
	Future	0.1	1	2	3
Plastic --	Present	0.4	0.8	1.6	3.5
	Future	0.2	0.4	0.8	1.6
Maximum moisture (%)		30	35	40	50
Minimum biodegradable organic matter (% dry wt)					
Present		20	25	30	35
Future		30	35	40	45

Heavy Metals -- The heavy metal content of compost has received the greatest amount of attention by the CEC and its member nations [12]. Table 6-7 presents a sampling of concentration limits that have been developed by various nations in Europe, as well as actual values from compost analyses. As shown in the table, the concentrations of heavy metals in compost from source separated MSW are much lower than those from the other MSW composts presented. Also presented, for comparison purposes, are heavy metal concentrations for compost prepared from plant residues and agricultural wastes; these show the lowest values.

Salinity and pH -- The following guidelines have been developed by the CEC for salinity and pH [12]:

Salinity	2 g salt/litre
pH	Range of 5.5 to 8.0 (compatible with plant growth)

6.1.2.2 France

Composting has been used for MSW treatment in France for years, and currently approximately 650,000 tonnes/year of MSW compost are produced. In 1987, the French Agency for Wastes Recovery and Disposal (ANRED) recognized the need to regulate MSW composting. ANRED's two-fold approach involved proposing a compost treatment scheme and developing specifications for two classes of MSW compost. "Quality certificates" are awarded to composts meeting the requirements for either Class A or B (see Table 6-8). Composts must also meet the French Standard NF U 44051 limiting maximum concentrations of heavy metal in soils [13].

6.1.2.3 Austria

Guidelines for compost quality were developed by the Standards Committee in Vienna, Austria, as early as 1984 [14]. The standards (ONORM S 2022) address the following areas: organic substance content, nutrient content, physical properties, plant tolerance, impurities, and heavy metals. Table 6-9 lists some of the parameters developed under ONORM S 2022, and their respective nominal ranges.

6.1.2.4 Switzerland

The environmental protection law in Switzerland regulates the quality of compost products by defining limits, method of control, and sanitation rules. Waste-derived compost is excluded from the market if it is of questionable quality. The criteria used for judging the quality of compost include physical properties, degree of maturity, contaminant level, particle size, and pollutant content [15]. A list of the pollutant limits is presented in Table 6-10.

6.1.2.5 Spain

The quality of commercial compost has been regulated in Spain as early as 1970. As shown in Table 6-11, early laws included parameters for moisture content, organic content, nutrients, and particle size. Regulations passed in 1988 are more stringent in nutrient content and also include maximum concentrations for potential toxic elements [16]. The data in Table 6-11 provide a comparison of national legal requirements from 1970 to 1988.

TABLE 6-6. Comparison of CEC Specifications for Minimum Levels of Nutrients in Compost with Actual Values from France (%, dry wt. basis).

	CEC Specifications [1]	Actual Values France [12]
Nitrogen	0.6	1.1
Phosphate	0.5	0.6
Potassium	0.3	0.6
Calcium	2.0	7.1
Carbonates	3.0	
Magnesium	0.3	1.0

TABLE 6-7. Maximum Permitted Concentrations of Heavy Metals in MSW Composts for Various Countries [12] (mg/kg, dry wt.).

	Belgium		The Netherlands		Federal Republic of Germany
	Food	Non-Food	1987-1992	1993-2003	
Zinc	1000	1500	1300	250	375
Lead	600	1000	500	150	150
Copper	100	500	400	50	150
Chromium	150	200	300	100	150
Nickel	50	100	60	50	25
Mercury	5	5	3	1.5	3.2
Cadmium	5	5	3	1.5	2.5

TABLE 6-8. Specifications for Two Classes of MSW Compost in France [13].

Parameter	Unit	Maximum Limits (dry wt)	
		Class A	Class B
Particle size	mm	40	40
Light plastics (size >5 mm)	%	1.6	2.5
Heavy particles (size >5 mm)	%	6	12
Total inert materials	%	20	35
Lead	ppm	800	800
Mercury	ppm	8	8
Cadmium	ppm	8	8
Nickel	ppm	200	200

TABLE 6-9. Partial Listing of Compost Quality Parameters Developed in 1984 for Austria [14].

	Unit	Nominal Range
Nutrients		
Total Nitrogen	% DS	0.5 to 1.5
Total Phosphate	% DS	0.4 to 0.8
Total Potassium	% DS	0.3 to 1.0
Calcium	% DS	2.0 to 12.0
Carbonates	% DS	3.0 to 20.0
Magnesium	% DS	0.5 to 3.0
Physical Properties		
Moisture Content	% FS	25 to 35
pH		7.0 to 8.5
Impurities		
Oversized Grain (11.2 mm)	% DS	0 to 3
Glass (2 mm)	% DS	0 to 3
Plastics (4 mm)	% DS	0 to 3
Heavy Metals		
Chromium	ppm DS	50 to 300
Nickel	ppm DS	30 to 200
Copper	ppm DS	to 1000
Zinc	ppm DS	300 to 1500
Cadmium	ppm DS	1 to 6
Mercury	ppm DS	1 to 4
Lead	ppm DS	200 to 900

DS = dry substance
FS = fresh substance

TABLE 6-10. Swiss Limits for Pollutant Content in Waste Compost [15].

Element	Limits (soluble, ppm)
Lead	1.0
Cadmium	0.03
Fluoride	25
Copper	0.7
Nickel	0.2
Zinc	0.5

TABLE 6-11. A Comparison of Legal Requirements for Compost Quality in Spain - 1970 to 1988 [6].

Parameter	1970	1988
Maximum moisture content (%)	40	40
Minimum organic content (%)	25	25
Minimum nitrogen content (%)	0.5	1
Particle size (% passing 25 mm)	90	90
Maximum heavy metal content (ppm)		
Cadmium	--	40
Copper	--	1750
Nickel	--	400
Lead	--	1200
Zinc	--	4000
Mercury	--	25
Chromium	--	750

6.1.2.6 Japan

The application of organic fertilizers on the land in Japan is controlled by the Ministry of Agriculture (MOA). The MOA enacted the Law of Fertilizer Control. According to the law, the maximum concentrations (in mg/kg, dry wt.) of heavy metals in the compost are as follows [17]:

Mercury	2.0
Cadmium	5.0
Arsenic	50.0

6.2 Compost Facility Siting and Approvals

Similarly to compost quality standards, regulations regarding the siting of compost facilities are, in many jurisdictions, still in the developmental stages. This is particularly true for MSW and yard debris composting. In lieu of regulations geared specifically to composting operations, many such facilities fall under the restrictions applied to solid waste facilities in general.

As defined in Table 6-1, the province of Quebec regulates certain aspects of compost siting, Regulations include restrictions regarding the surrounding area; facility identification; types of wastes; waste disposal; and leachate control. Interim internal guidelines are in effect in Ontario, although facilities producing less than 200 tonnes/day of waste are exempted from the Environmental Assessment Act. Other provinces either do not regulate compost siting or examine each project on a case-by-case basis.

In the U.S., the responsibility for facility siting is that of the State or municipal government. Even though most States have not as yet established specific regulations governing the siting and approval of sludge and MSW composting facilities, all States have general construction and environmental protection laws that apply to compost facilities. These laws enable the States to regulate proposed facilities and prevent them from causing an environmental hazard or nuisance.

The States listed in Table 6-12 have developed specific regulations governing the operations and process control of sludge and MSW composting. The table summarizes the requirements of each State. Except as noted on the table, the steps involved in the permitting process for a compost facility are similar to those in the following generic description: Initially, a regional map and a site plan are required. These regional maps should show the site in relation to zoning and regional use, highways, population centres, airports, bodies of water, and other pertinent features. The site plan should show the facility layout, drainage and water well features, roads, and property lines. The operational plan must begin with a detailed description of the wastes to be processed and an anticipated waste quantity and traffic flow summary. The facility design must be described, including the type and size of equipment and the expected processing rates. Provisions must be made to meet the process to significantly reduce pathogens (PSRP) and the process to further reduce pathogens (PFRP) which involve time and temperature standards of composting. Other requirements include drainage and leachate control systems to protect surface and groundwater. air pollution control devices, and a marketing and distribution plan for the finished compost. Additionally, the site must have a sign or registration clearly stating the name of the owner and operator of the facility.

TABLE 6-12. Facility Siting and Approvals for Sludge and Municipal Solid Waste Composting in the U.S.

	New York [4]	Florida [7]	New Jersey [18]	Pennsylvania [19]	Delaware [10]
Site location acceptability and zoning approval	Yes	Yes	Yes	Yes	Yes
Engineering map of site	Yes	Yes	Yes	Yes	Yes
Description of wastes	Detailed	Yes	Yes	Yes	Yes
Operational plan	Yes	Yes	Yes	Yes	Yes
Schedule of operations	Yes	Yes	Yes	Yes	NS
Traffic load	Yes	Yes	Yes	Yes	NS
Equipment description	Yes	Yes	Yes	Yes	Yes
Storage description	Yes	Yes	Yes	Yes	Yes
Processing and mat’l flow	Yes	NS	Yes	Yes	NS
Monitoring plan	Yes	Yes	Yes	Yes	Yes
Aeration capacity	Yes	NS	Yes	NS	NS
Mass balance	Yes	Yes	Yes	Yes	NS
Description of PSRP PFRP [a])	Yes	NS	Yes	NS	Yes
Groundwater protection runoff and leachate control	Yes	Yes	Yes	Yes	Yes
Product marketing or distribution plan	Yes	General	Yes	Yes	Yes
Air emission control plan	Yes	Yes	Yes	Yes	Yes
Specific ownership	Yes	Yes	Yes	Yes	NS
Personnel descriptions	Yes	Yes	Yes	Yes	NS

NS = not specified

a) PSRP = Process to significantly reduce pathogens
PFRP = Process to further reduce pathogens

Yard waste composting facilities are generally viewed as posing a minor environmental risk. Nevertheless, some U.S. States do have formal permitting procedures for these facilities (see Table 6-13). The regulations are similar to those for MSW and sludge composting, but usually with less detail and specific operational requirements. The regulations are broad enough to allow operators to select a level of technology and composting procedure appropriate to their needs. The primary concern with yard waste composting is surface and groundwater pollution from leachate. Drainage and leachate control standards are therefore the central focus of yard waste composting legislation.

A few states (e.g., Delaware, Pennsylvania, and Michigan) have specifically exempted all yard waste composting facilities from the permitting process, but nonetheless have environmental pollution standards that the facilities must meet [10,20,24]. Most central and western states do not have a specific permitting procedure in place for yard debris compost facilities.

Many States have developed exemptions from the permit process for small generators of yard waste compost or operators of standard farming composting practices. Florida, for example, has exempted backyard composting, normal farming operations, and facilities which process yard waste for other uses such as mulch [7]. New York has exempted facilities that compost less than 2,295 m^3 of yard waste and those at which only food processing waste and/or animal manure are processed [4]. Wisconsin requires no permit for backyard and neighbourhood composting sites less than 38 m^3 in size [21] Due to New Jersey's ban on leaf landfilling, the State has granted during 1989 an emergency exemption for the full leaf composting permit requirement. Communities have been allowed to get a temporary approval to operate while their formal permits were under review by the Department of Environmental Protection [22].

6.3 Health and Safety Requirement

Health and safety requirements for composting operations often fall under the regulations in effect for solid waste disposal facilities or wastewater treatment plants (for sewage sludge composting). The primary focus of the requirements is that the facility be operated in a safe manner and nuisance control measures be taken when appropriate.

Safety regulations in Canada and the U.S. include fire safety procedures, such as the provision of hoses and extinguishers around the piles and equipment. Nuisance control measures generally include vermin and vector control, odour control, dust mitigation, and litter control procedures. Non-processibles and other material not suitable for composting are usually not allowed to be stored for any length of time on the facility grounds. Health and safety requirements at yard waste composting sites are less stringent and specific than those for sludge and MSW composting, since these facilities involve less machinery and handle less putrescible waste.

Examples of public health and safety regulations concerning MSW and sludge composting operations for several U.S. States are presented in Table 6-12. Although it is generally recognized worldwide that "operative conditions in composting installations are warranted which may safeguard the health of the operators" [12], little specific information is available in the literature regarding procedures for doing so.

The potential hazards to workers from airborne pathogens in composting facilities is addressed by P. Boutin and J. Moline [25]. They stress the importance of incorporating dust control measures in the design of the facility. Specifically, the following recommendations are made: prohibit hand sorting of refuse; enclose the main dust emitting devices; equip refuse and compost handling places with superpressured cabins supplied with fresh filtered air; aid dust dilution by increasing air circulation through the use of sheds instead of enclosed premises; and isolate process premises from hygiene rooms [25].

TABLE 6-13. Facility Siting and Approvals for Yard Debris Composting in the U.S.

	Connecticut [20]	Florida [7]	Wisconsin [21]	New York, [4]	New Jersey [22]	Pennsylvania [23]	Michigan [24]
Type of Permit Required	leaf composting facility permit	Permit to construct/ operate *a* composting facility for the production of organic Products	Required waste composting permit (over 50 yd)	Yard waste composting permit	Leaf composting facility permit	No formal permit guidelines	Not required
Guidelines or standards developed	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Engineering Plan Site Map	Yes	Yes	Yes	Yes	Yes	Yes	No
Operations & management plan	Yes	Yes	Minimal	Yes	Yes	Yes	No
Water Safety Protection Plan	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Product testing or statistics	Yes	Assumed	No	Must be stable	Must be stable	Must be registered	No
Health and Safety	Yes	Yes	Yes	Yes	Yes	Yes	No

6.4 Hazardous Waste Handling, Storage, and Disposal

It is the consensus worldwide that wastes contaminated with hazardous materials should not be used for the preparation of organic soil amendments [1]. Source separation of feedstocks to the compost operation is the recommended method of reducing the introduction of materials that would potentially contaminate the compost [1,12,14,26,27]. Alternatively, pre-processing of the solid wastes is recommended to restrict composting to the organic fraction by removing inerts prior to composting and thus limit the transfer of heavy metals to the compost product. [1,12].

In the provinces of Ontario and Quebec, the types of wastes that can be processed at a compost facility are restricted (see Table 6-1). Restrictions address biomedical waste, and other types of hazardous and toxic wastes.

In the U.S., Florida has legislated that hazardous waste, used oil, and wastes containing asbestos should not be processed into compost except for small quantities normally found in household waste. It is the responsibility of plant operators to reject any loads found to contain the hazardous waste materials [7].

In Austria, standards have been developed (ONORM S 2100) which specify the special and hazardous wastes that can be composted safely [14].

Regulations have been developed by the State of New York to limit the amounts of hazardous wastes entering MSW compost by requiring that a household hazardous waste collection system be in place in any residential area serviced by a MSW composting facility. The household hazardous waste collection system must be approved by the New York Department of Environmental Conservation and operated according to Section 360-1.7(b)(6) of the Part 360 Solid Waste Management Facility Regulations. The regulations specify that an approved site be utilized for clean up days of household and farming hazardous waste. The site must be fenced, staffed by qualified personnel, and operated in accordance with approved segregation and packaging plans [4].

6.5 Summary

Several regulations have been developed to control the use of composts. Some European countries have had regulations for a number of years. In addition, the CEC has taken the lead in trying to establish regulations common to all member countries. In most cases, European regulations are more stringent than those in the U.S.

In the U.S., the EPA has been heavily involved in the development of guidelines controlling the treatment and distribution of sewage sludge products. The guidelines currently are under evaluation and are expected to be modified.

Regulations applying to composts produced from MSW and yard debris have been developed by some states. In most cases, the regulations have been developed without the benefit of having the composts tested and evaluated. Unlike sewage sludge compost, limited tests have been conducted on MSW and yard debris composts. Thus, in several cases, the regulations were based on those for sewage sludge.

After regulations had been developed in one or two states, other states followed suit by adapting those regulations to their particular situation. Consequently, the latest regulations are modifications of those developed in states like New York and Minnesota. Most regulations limit the use of the composts based on the concentration of heavy metals and some toxic organic compounds. Very few states, if any, have carried out agricultural or horticultural tests on the finished products.

Compost made from yard debris has very few restrictions and regulations.

Guidelines for permitting, siting and operating composting facilities are essentially the same *as* those for any other solid waste management facility. The guidelines currently are being tested and are in a process of evolution. States that do not have these guidelines in place are relying on guidelines developed for other states.

Most states are encouraging the development of yard debris compost projects. Consequently, requirements for permitting and siting are not as stringent as those for other solid waste management facilities.

As more composting facilities are built, more states will institute guidelines that are specifically developed for their particular conditions (i.e., climate, population). Furthermore, established regulations and guidelines will be modified to reflect the nature of the compost feedstock as well as available processes.

In Canada, Ontario and other provinces have not yet adopted regulations or guidelines on compost quality. Ontario and some other provinces do, however, have guidelines on siting of new composting facilities.

6.6 References

[1] Zucconi, Franco, and Marco de Bertoldi, "Specifications for Solid Waste Compost." BioCycle, 28(5):56-61 (May/June 1987).

[2] Portland Area Compost Products Market Study, prepared for the Metropolitan Service District, Portland, Oregon, by Cal Recovery Systems, Inc., October 1988.

[3] "EPA Sludge Disposal Regulation Proposed," BioCycle, 30(3):44-47, (March 1989).

[4] Six NYCRR. Part 360 Solid Waste Management Facilities. New York State, Department of Environmental Conservation, Subpart 360-5, December 31, 1988.

[5] Regulation for the Land Application of Sludge and Septage, Massachusetts Department of Environmental Quality Engineering, 310 CAR 32.00, November 10, 1983.

[6] Regulation of Water Supply. Sewage Disposal and Solid Waste, Subtitle 04, Maryland Department of the Environment.

[7] Criteria for the Production and Use of Compost Made from Solid Waste, Florida Department of Engineering Regulations, Workshop No. 2, Draft Regulations, May 1, 1989.

[8] Guidelines for the Agricultural Utilization of Sewage Sludge, The Rules and Regulations of the Department of Environmental Resources, Commonwealth of Pennsylvania, Pg. 2, May 1988.

[9] Part 391, Design Criteria for Sludge Application on Land, Chapter II, Subtitle C, Title 35, Illinois Environmental Protection Agency, January 1, 1984.

[10] Guidance and Regulations Governing the Land Treatment of Wastes, State of Delaware Department of Natural Resources and Environmental Control, Subsection 1003, p. 198, August 1988.

[11] Domestic Sewage Sludge Regulations, Colorado Department of Health, 5CCR, 1003-7,1986.

[12] L'Hermite, P., "State-of-the-Art of Composts Systems: Current Situation in Europe and Future Outlook," Presented at the International Symposium on Compost Production and Use, S. Michele All'Adige (Trento), Italy, June 1989.

[13] Merillot, J.M., "Recycling Organic Municipal Wastes in France," BioCycle, 30(7):30-31(July 1989).

[14] Lutz, Willibald, "Austria's Quality Requirements for Solid Waste Compost," BioCycle, 25(5):42-44 (July/August 1984).

[15] Mayer, M., H. Hofer, and U. Maire, "Trends in Yard Waste Composting," Biocycle, Vol. 29 (July 1988).

[16] Sana, J., F. Giro, M. Soliva, and P. Florensa, "Approccio Metodologico Nella Valutazione Della Qualita del Compost Della Catalogna (Spagna)," Presented at the International Symposium on Compost Production and Use, S. Michele All'Adige (Trento), Italy, June 1989.

[17] Kubota, H. and K. Nakasaki, "State of the Art of Compost Systems: The Current Situation and Future Outlook in Japan," Presented at the International Symposium on Compost Production and Use, S. Michele All'Adige (Trento), Italy, June 1989.

[18] Chapter 26, New Jersey Division of Waste Management, Section 7:26-2B.6, Supplement October 19, 1987.

[19] Guidelines for Leaf Composting Facilities, Pennsylvania Department of Environmental Resources, Bureau of Waste Management, June 7, 1988.

[20] Guidelines for Preparation of an Application for a Permit to Construct and Operate a Leaf Composting Facility, State of Connecticut Department of Environmental Protection, September 1988.

[21] Wisconsin DNR Codes and Guidance Concerning Composting Sites, State of Wisconsin, October 1987.

[22] Compost Permit Requirements, New Jersey Department of Environmental Protection/Division of Solid Waste Management, September 1, 1987.

[23] Environmental Quality Board Municipal Waste Management Regulations, Pennsylvania Bulletin, Vol. 18, No. 15, Chapter 281, Composting Facilities, p. 1793, April 1988.

[24] Personal Communication, Ware Koser, Michigan Department of Natural Resources. Department of Waste Management, June 1989.

[25] Boutin, P., and J. Moline, "Health and Safety Aspects of Compost Preparation and Use," Compost: Production, Quality and Use, M. de Bertoldi, M.P. Ferranti, P. L'Hermite, and F. Zucconi, eds., Elsevier Applied Science, 1987.

[26] Golueke, Clarence G. and Luis F. Diaz, "Quality Control and Waste Management,"BioCycle, 30(7):65-67 (July 1989).

[27] Reijenga, Femke, "Separate Collection of Compostables," BioCycle, 30(7):62-64 (July 1989).

7.0 OTHER EMERGING TECHNOLOGIES

7.1 Irradiation of Sewage Sludge for Composting

7.1.1 Introduction

Municipal sludge contains many nutrients beneficial to plant growth - nitrogen, phosphorous and trace minerals are examples. Advantage can be taken of these fertilizer or soil conditioning properties, provided that some potentially harmful sludge components are reduced or eliminated. Regulations generally encourage sludge use, however, cost effective and reliable pathogen and parasite elimination or reduction can be a stumbling block to achieving more successful utilization programs.

Research and long-term operating units have demonstrated that irradiation is an effective means for reducing or eliminating pathogens and parasites in sewage sludge and other wastes to levels where reuse in public areas meets criteria for protection of the public health [1]. The irradiation process does not increase the extractability and plant uptake of a broad range of nutrients and heavy metals from sludge-amended soils [2]. However, it does eliminate the hazards associated with pathogen and parasite contamination when applying sludge to land.

The key to understanding why radiation processing is being used is to remember that gamma radiation is an effective and readily available method of destroying microorganisms. It is for this reason that irradiation is considered as a viable pasteurization alternative for sludges and other non-toxic wastes.

7.1.2 Sludge Irradiation Experience and Regulation

Since 1975, scientists at New Mexico State University in New Mexico, USA, have been using irradiated sewage sludge in an extensive research program encompassing biology, crop and soil sciences, animal sciences and agricultural economics [2]. The sludges used in all research projects were first irradiated at Sandia National Laboratory's 8-ton-per-day pilot plant irradiator. Jointly sponsored by the U.S. Environmental Protection Agency and the Department of Energy, the research work at Sandia has shown that irradiation of dewatered sludge effectively eliminates pathogens without affecting the beneficial soil conditioning qualities of sludge (see results in Section 7.1.3).

Composting tests carried out in Japan have found that CO_2 production almost ceases within two or three days in irradiation-pasteurized sludge compost piles, as opposed to more than 10 days in unpasteurized sludge compost piles [3]. This significantly longer composting time in unpasteurized sludge is due to the slowing down of composting bacteria action when high temperatures are maintained to eliminate pathogens.

The process has also met with World Health Organization (WHO) approval [4]. A WHO working party on sewage sludge disinfection processes recommends providing for a minimum irradiation dose of 500 krad (0.5 Mrad) for unconstrained use of sludge.

A full-scale sewage sludge, irradiation-pasteurization plant has been operating in Geiselbullach, West Germany, since 1973. The plant is designed to process sludge generated by a region whose population is 240,000 people. Plant operators have reported that this pasteurization process is economically attractive when compared to other available processes and that irradiation is safe, effective and reliable [3]. Regulations regarding the treatment and use of municipal sewage sludge have received increasing attention around the world. The U.S. Environmental Protection Agency, for instance, has designated gamma-irradiation treatment as a method of pathogen reduction in its regulations [6]. EPA land application criteria stipulate that irradiation, when preceded by a process such as anaerobic digestion, effectively protects public health from sludge-borne pathogens.

In other countries, the Swiss Parliament has decreed that sewage sludge must contain no more than 100 enterobacteria per gram and no viable infectious worm eggs at the time of delivery if sludge is used as a fertilizer on grazing areas and areas used for horticulture [7]. In the Federal Republic of Germany, sewage sludge must be treated with a state-approved process to render it non-infectious before it can be applied [8].

7.1.3 Effects of Irradiation on Pathogens

Numerous pathogen inactivation studies have confirmed that gamma radiation will kill bacterial and fungal pathogens, viruses and parasites found in sludge, but the sensitivities to irradiation of different pathogens vary.

Pathogenic fungi can grow in sludge, particularly during composting. The sensitivity of one of these, *Aspergillus Fumigatis*, to gamma irradiation was studied at Sandia National Laboratories 19]. A D_{10} value (the dose required to reduce contamination levels by 90%) of 0.05 to 0.06 hind was obtained for fungal spores, indicating that irradiation is an effective method of destroying them in sludge. The ova and cysts of protozoan and helminthic parasites sometimes found in wastewater are resistant to inactivation by physical and chemical processes. These parasites are not common to all sludges, but may be found where local morbidity is sufficient to provide a source to the wastewater treatment stream. The resistant ova and cysts are heavier than bacteria and viruses, so a great majority will settle into sludge during primary clarification.

Dosages of 0.2 Mrad consistently caused reductions of three or more orders of magnitude in viable parasitic eggs, whether in liquid or composted sludge.

Results obtained from the West German sludge irradiator indicate that a dose of 0.3 Mrad is sufficient to inactivate two to three orders of magnitude of enterococci (fecal streptococci) and five to six orders of magnitude of enterobacteria (fecal and total coliform) [5].

Up to 1×10^5 enteric viruses/g are reportedly excreted by infected individuals and over 1×10^5/L have been recovered from raw wastewater. Studies have shown that anaerobic digestion removes about 90% of detectable viruses from sludge [9]. But because viruses are small and have simple chemical structures, they prove to be most resistant to irradiation.

Biologists at New Mexico State University have shown, however, that when irradiation-pasteurization is coupled with a treatment such as anaerobic digestion, then viruses are reduced below detectable limits [1].

A review of the research/studies that have been published to date yields the following information on chemicals in irradiated sludge.

In a report presented to the International Atomic Energy Agency at Vienna, on "High Level Radiation in Waste Treatment'', researchers Dr. Lessel and Dr. Suess stated "The irradiation treatment does not change significantly the chemical compounds of the sludge. This observation holds true also for organic nitrogen compounds ... However, sometimes the dewatered irradiated sludge seemed to be richer in phosphate than the non-irradiated sludge ... This may be explained by an indirect effect of the treatment, rather than a direct one."[10]

In a 1979 West German study of irradiated sludge, it was concluded that, "As the irradiation takes place at temperatures between 25° and 30°C, no breakdown of organic nitrogen compounds is induced and no obnoxious smells are registered" [5].

Research on a sludge irradiator, largely carried out by a number of departments at the New Mexico State University, included chemical studies, with results as follows;

- The irradiation process does not increase the extractability and plant uptake of a broad range of nutrients and heavy metals from sludge-amended soils. [11]

- Soil chemistry data from experiments with herbicide residues, PCBs and pthalate esters have shown degradation of the organic residues, but in no case was the persistence of these compounds extended in sludge-amended soil. [11]

In addition, the University carried out a five-year study of range beef cows and breeding ewes fed feed supplements containing 7 to 50% gamma irradiated sewage sludge. The ewes were fed the sludge supplement continuously over the 5 year period, while the cows received the supplement for 4 months of each year for 5 years. Results reported included [12]:

- long-term consumption of gamma irradiated sewage solids caused no changes in activities of enzymes for biotransformation of xenobiotics suggestive of toxicosis; and

- there were no lesions of toxicosis evident at slaughter, nor any buildup of heavy metals and refractory organic residues in organs and tissues.

In addition to the research that has already been carried out, please note that the University of Guelph, Ortech International, the Ontario Veterinary Council and the Whiteshell Nuclear Research Establishment in Manitoba are involved in a two-year study of irradiated and un-irradiated municipal sewage sludge. Toxic organics are included in this study, which should yield more in-depth data.

7.1.4 Summary

A typical sludge management system consists of processes for thickening, stabilization, dewatering, disinfection and disposal Composting can assist with sludge/waste stabilization, dewatering, disinfection and preconditioning of the sludge for composting. Irradiation provides an effective and reliable means of disinfection. When partly dewatered sludge is pasteurized by irradiation, the subsequent composting process can be completed more quickly, more easily and more cheaply.

Sludge irradiation will likely be most widely used as an add-on to facilities where a stabilization process, such as anaerobic or aerobic digestion, already exist and a disinfection process must be added to promote the sale of the sludge. Sludge cold pasteurization me; enhance the storage and long-distance transportation characteristics of sewage sludge.

7.2 References

[1] "Irradiation as a Means to Minimize Public Health Risks from Sludge-Borne Pathogens", J.G. Yaeger, R.T. O'Brien (1983) in J. Water Pollution Control Federation, 55, 977-983.

[2] "Sewage Sludge: A Beneficial Byproduct", G.A. O'Connor, NMSU, Las Cruces, New Mexico (1980).

[3] "Economic Feasibility of Irradiation-Composting Plant for Sewage Sludge", S. Hashimoto, K. Nishimura, S. Machi; Takaski Radiation Chemistry Research Establishment, Japan Atomic Energy Research Institute, Takasaki, Gumma 370-12, Japan (1987).

[4] "Survey of Sewage Sludge Disinfection Processes", Commission of the European Communities, Environment and Waste Recycling Programme (1987).

[5] "Gamma-Irradiation for Disinfection and Conditioning of Sewage Sludge - The Geiselbullach Demonstration Project", T. Lessel, A. Seuss, E. Engimam; Abwasserverband Ampergruppe, Haupstr. 37, D8031, Eichenau (1979).

[6] United States Environmental Protection Agency (1979), Title 40, Code of Federal Regulations, Part 257.

[7] Swiss Parliament, Sewage Sludge Decree, 18 April 1981.

[8] Federal Republic of Germany, Sewage Sludge Decree, 25 June 1982.

[9] "Pathogens in Sludge: Occurrence. Inactivation and Potential for Regrowth", R.L. Ward, G.A. McFeters, J.G. Yaeger, Sandia National Labs, New Mexico (July 1984).

[10] "Technical and Economical Aspects of Irradiation", A. Suess, T. Lessel and A. Haisch; Bayerische Landesanstalt fur Bodenkultur unjd Pflanzenbau, Munchen (1982).

[11] "Irradiation of Municipal Sludge for Agricultural Use", S.B. Ahlstrom, CH2M Hill Inc., Albuquerque NM. Published in Radiation Physics & Chemistry Journal, Vol. 25 (1985).

[12] "Final Technical Completion Report", Contract #DE-AC04-83AL21776, New Mexico State University.

8.0 ALTERNATIVES TO COMPOSTING

8.1 Introduction

Several alternatives exist that can handle organic wastes other than composting. These alternatives are briefly discussed below.

8.1.1 Animal Feed

Historically, livestock have been fed kitchen scraps and food byproducts. These practices continue today but on a much smaller scale. Approximately one percent of the United States hog production is raised on such waste feeding operations (BioCycle, 1985).

The nutritional requirements of hogs are similar to humans and therefore hogs are ideal for utilizing these wastes. Carcass quality is not significantly different between animals fed food wastes and animals fed grain.

Before the food waste is fed to the hogs, care must be taken to guard against inducing human and animal health problems. Most waste food classes must be steamed a minimum of 30 minutes at 212°F.

Farmers collect food wastes from local restaurants, cafeterias and food processors. Food waste recycling projects are only viable when the farms are located close to a concentration of food waste producers.

It is not feasible to include residential food waste in a hog waste feeding system due to petrification problems resulting from the long residence time in the home before the waste is put out for pick-up.

8.1.2 Biogas Production

8.1.2.1 Introduction

Biogas is generated when microbes break down organic material under anaerobic conditions. The biogas consists mainly of methane and carbon dioxide with approximately 65% of the gas consisting of methane. Its gross heat value is approximately 7 kwh/m^3. The fermentation period to produce biogas is 15 to 20 days. The biogas can be used as fuel in furnaces or boilers. The remaining digestate can be spread on fields.

The major advantages of anaerobic digestion are:
- low sludge production; and
- reactor remains stable *even* when shut down for several months.

The limitations of anaerobic digestion are:
- the process is slow to start-up;
- slow recovery from accidents; and
- requires careful surveillance.

Anaerobic digesters are usually used to treat wastes from cattle and hog raising stations, high BOD food processing wastes and sewage sludges.

8.1.2.2 Biogasification of Municipal Solid Wastes

Studies at the Sanitary Engineering Research Laboratory (SERL) of the University of California (Berkeley) investigated the reduction and stabilization of the organic fraction in municipal solid waste via anaerobic fermentation [1-4]. The SERL digestion studies led to the conclusion that the organic component of MSW can be readily digested with the exception of wood and to some extent printed paper. At an organic loading rate of about 1.12 g volatile solids/L-d (VS/L-d), a detention time of 30 days and a temperature of 35°C, approximately 0.4-0.6 L of gas per gram of volatile solids introduced (L/g VS) can be expected.

Investigations to evaluate the feasibility of digesting mixtures of sewage sludge with the entire organic fraction of MSW were carried out in the early 1970s [5-6]. Gas production fluctuated from 0.12-0.45 L/g VS added depending on loading rate, temperature and detention time.

Other experiments were conducted by Klass and Ghosh [7-8] centred on the digestibility of sludge when mixed with the organic fraction of refuse. Gas productions equivalent to 280 to 570 L of methane per person per day were reported.

The Dynatech R&D Corp. [9] team came to the conclusion that biogasification was both technically and economically feasible.

A demonstration project in Pompano Beach, Florida evaluated the commercial feasibility of digesting the organic fraction of refuse. Waste Management Inc., under contract with the Department of Energy, evaluated the technology and economics involved in converting up to 90 tonnes of refuse per day into methane gas.

Gossett and McCarty [10] investigated suitable ways of enhancing the anaerobic biodegradability of refuse. They found that exposing refuse to a temperature of 133°C and a pH of 1 over a 3 hour period could almost double the biodegradability of digested refuse. The additional expenditure in energy required to attain the high temperatures may exceed the amount of resulting energy from the enhancement in gas production.

A study at the University of California (Berkeley) used the organic fraction segregated in a resource recovery system developed by the University. The study allowed for the integration of various unit processes such that valuable materials (e.g. ferrous metals and papers) could be recovered for refuse. Each process was selected such that the residue from one became the input to a second process [11].

8.1.3 Landfarming

Landfarming is a broad term adopted fairly recently by the waste management profession referring to a method of destruction or disposal of an undesirable waste. In the method, the soil is the principal agent of destruction. The soil is such an agent in that it not only is the medium, but it also is a reservoir of macro- and micro-organisms that break down the residue. Although the designation "farming" may be somewhat misleading, it is useful in that it is a means of distinguishing between the practice of using manure, crop residue and sewage sludge as a soil amendment or source of fertilizer elements and the relatively recent innovation in which the role assigned to the soil is to serve as an agent of destruction and stabilization. Furthermore, use of landfarming in the context of composting also is somewhat far-fetched. One relation between composting and landfarming is that both involve waste destruction and stabilization. Another equally tenuous relation is that composting and landfarming do to a limited extent share several parameters and requirements.

In the past decade, a considerable amount of research and number of applications related to landfarming have been and are directed to its potential in the disposal of petroleum sludges. A more recent development is a gradual expansion of research effort directed to the landfarming of other hazardous wastes.

8.1.3.1 Municipal Solid Waste

Most of the formal research on landfarming municipal solid wastes took place in the late 1960s at the University of California (Berkeley) [12, 13]. The underlying concept of landfarming investigated by the University was based on the rationale that land should be an essential part of the treatment. However, the manner of the treatment should be such that the land need not be permanently dedicated to wastes disposal, as is the case with landfill. According to this rationale, the land serves as a means of processing rather than of disposal. The processing is accomplished by adapting the bioxidation phase of the growth-decay cycle prevailing in soil to the oxidation and stabilization of the organic matter in the wastes. With such an adaptation, the land is loaded to the limit of its ability to accept wastes without disrupting the growth-decay cycle. (Exceeding this limit leads to production of objectionable odours and other nuisances.) A variation would be sequential cropping and waste treatment.

One application of the concept involves two key steps: 1) minimally process the wastes; and 2) immediately incorporate the processed wastes into the soil. The name given the system by its developers, "low-cost biostabilization" is used in this report. The term is apropos because this particular system includes variations that range from those in which only a minimum of segregation and grinding precede incorporation of the refuse into the soil to those in which some composting precedes incorporation. In practice, a given plot of land receives a loading of ground raw and unsegregated refuse or of roughly composted refuse once or twice each year throughout the time in which the site is dedicated to waste disposal. The frequency of the loading is a function of the rate of decomposition or stabilization of the wastes in the soil.

When the time comes to divert the land to another use, loading is stopped and the land is allowed to recover. Nondegradable material remaining exposed on the soil is removed and buried elsewhere. Inasmuch as only the top 1 to 2 ft of the land would be involved, settling would be negligible and the land could be put to a different use immediately.

In the University study, each plot received solid waste once each year. However, to represent a real-life situation in which refuse is produced and must be processed year-round, waste was applied to one group of plots in the summer, to a second group in the autumn, a third group in the winter, and a fourth group in the spring. The organic material was spread on the land, after which the land and its surface layer of refuse was tilled with a heavy-duty tiller. At loadings above 300 tons/acre-yr, it was necessary to remove the top 6 in. of soil before applying the refuse, return this soil to the top of the applied wastes, and, finally, to till and mix soil and refuse. Therefore, with such high loadings, specialized equipment would be required.

Results obtained in the research indicated that: 1) difficulties would be encountered in applying refuse during wet seasons and also in incorporating large amounts of refuse into the soil; and 2) the aesthetics of the operation would be unacceptable as would be associated vector and rodent problems. In short, a full-scale operation would take on many of the objectionable characteristics of an open dump.

8.1.3.2 Petroleum and Other Hazardous Wastes

Landfarming of petroleum and other hazardous wastes differs from that of municipal solid waste in that it usually calls for: 1) frequent working of the soil to ensure satisfactory aeration; 2) the addition of macronutrients that might be in short supply in the wastes; 3) a long-term dedication of land area; and 4) a more specialized microbial population. A fifth difference arises from the involvement of hazardous materials. Because of this involvement, operation and maintenance controls are more rigorous and must be carefully observed. All gaseous, liquid, and solid emissions must not be released into the environment without having been rendered innocuous. The present trend among local, state, and federal regulatory agencies is to require the operation to be sheltered such that control is had at all times on all emissions, beginning with delivery of the waste and ending with the completion of treatment. In the event that treatment does not render the product completely innocuous, the potentially hazardous treatment product must be stored or disposed at some appropriately regulated site.

Landfarming procedures vary with the type of waste to be treated. Oily wastes (e.g., sludges from petroleum storage tanks) are spread upon the field and then are disked into the soil to a depth determined by the need to maintain aerobiosis, i.e., not deeper than 15 to 18 cm (6-7 in.). Frequency of disking is determined by the fact that breakdown of oily wastes occurs only under aerobic conditions. (The situation may differ somewhat with certain hazardous wastes (chlorinated hydrocarbons). Such wastes may require an anaerobic phase in addition to the aerobic phase. The sequence of the two phases differs according to the waste requiring treatment.)

Retention times usually are in terms of 12 to 24 months.

Microbial Population -- Broadly speaking, for almost every type of organic hazardous waste manufactured thus far, a particular species of microbe capable of breaking down that waste can be isolated from the soil [12-15]. Thus, most of the so-called breakthroughs regarding hazardous waste and the microbes to break them down actually have already been made, but without fanfare. The practical significance of the existence of such microbes in nature is that in landfarming, particular strains of microbes needed are indigenous, albeit as minute populations. On the other hand, the real problems are to identify the factors that slow the process and develop technologically and economically feasible means and ways of coping with them. In other words, the engineering aspects constitute the biggest problem.

Difficulties of a biological nature are the poor ability of the desired species to compete under natural conditions with other species present in the soil. Compensating for this inability usually takes the form of setting up enrichment conditions, i.e., conditions favourable to the desired species, but less so or even inhibitory to potential competitors. This problem of competition and ability to thrive under practical and economical conditions is the major obstacle to practical use of "engineered" microorganisms.

Because the indigenous active strains of microbes usually are present as minute populations, incorporation of the waste into the soil usually must be followed by a lag period. The lag period is the time in which particular strains adapt to the waste and proliferate. The lag period can be materially shortened by repeatedly using the same land area, inasmuch as the microbial populations developed in the preceding treatment cycle will be present.

8.2 References

[1] Golueke, C.G. and McGauhey, P.11., Comprehensive Studies of Solid Wastes Management, 2nd Annual SERL Report No. 69-1, Sanitary Engineering Research Laboratory, University of California, Berkeley, 1969.

[2] Chan, D.B. and E.A. Pearson, Comprehensive Studies of Solid Wastes Management: Hydrolysis Rate of Cellulose in Anaerobic Fermentation, SERL Report No. 703, Sanitary Engineering Research Laboratory, University of California, Berkeley, 1970.

[3] McFarland, J.M. *et al*, Comprehensive Studies of Solid Wastes Management, Final Report, SERL Report No. 72-3, Sanitary Engineering Research Laboratory, University of California, Berkeley, 1972.

[4] Klein, S.A., "Anaerobic Digestion of Solid Wastes," Compost Science, Vol. 13, No. 1, January-February 1971, pp. 6-11.

[5] Pfeffer, J.T., "Reclamation of Energy from Organic Refuse", Solid Waste Program, EPA Grant No. EPA-P-800776, Department of Civil Engineering, University of Illinois, Urbana, Ill., April 1973.

[6] Pfeffer, J.T., "Anaerobic Processing of Organic Refuse", Proceedings, Bioconversion Energy Research Conference. Institute for Man and His Environment, University of Massachusetts, Amherst, Mass., 1973.

[7] Klass, D.L. and Ghosh, S., "Fuel Gas from Organic Wastes", Chemtechnology, Vol. 3, November 1973, pp. 689-698.

[8] Ghosh, S. and Klass, D.L., "Conversion of Urban Refuse to Substitute Natural Gas by the Biogas Process", presented at Fourth Mineral Waste Utilization Symposium, Chicago, ILL, 1974.

[9] "Fuel Gas Production from Solid Waste, 1974 Semi-Annual Progress Report", NSF Contract C-827, Dynatech Report No. 1151, 1974.

[10] Gossett, J.M. and McCarty, P.L. "Heat Treatment of Refuse for Increasing Anaerobic Biodegradability", NSF Grant GI-43504, Dept. of Civil Engineering, Stanford University, 1974.

[11] Diaz, L.F. et al., "Biogasification of Municipal Solid Wastes", Journal of Energy Resources Technology, Vol. 103, June 1981, pp. 180-185.

[12] Ed. G.B. Brown, G.B. Evans, Jr, B.D. Frentrup, "Hazardous Waste Land Treatment",Butterworth Publishers, Boston-London, 692 pp., 1983.

[13] E.J. Opathen, H.K. Howard, and J.J. Bond, "Biological Treatment of Leachate from a Superfund Site," Environmental Progress, 8(1)1248 (February 1989).

[14] J.B. McDermott, et al, 'Two Strategies for PCB Soil Remediation: Biodegradation and Surfactant Extraction," Environmental Progress, 8(1):46-51 (February 1989).

[15] M.R. Overcash, "Decomposition of Toxic and Nontoxic Organic Compounds in Soils, Ann Arbor Publishers, 455 pp., 1981.

9.0 CONCLUSION

This study has demonstrated that composting is being recognized as a viable waste management alternative in many European countries and the North America. As a result, many different technologies have been developed to separate compostable material from the municipal waste stream and to accelerate the process.

Composting technologies can be broadly divided into four groups: turned windrow, static pile, in-vessel and hybrid. Feedstocks range from using organic material from the municipal solid waste stream to sewage sludge, either separately or mixed together. Industrial organic wastes and sludges are also being used as composting feedstocks where conditions are economically favourable or mandated by circumstance.

Little information is available in the literature concerning the construction and operation of composting facilities in Canada. It is difficult to make an economic comparison in Canada of operating facilities and composting technologies used in other countries due to: climate differences, variable wages, equipment availability/sharing, accounting practices and variable land costs.

The reported operation and maintenance costs for sludge composting facilities ranges from $ 40 to $ 54 per dry tonne. Reported operation and maintenance costs for yard waste composting facilities range from approximately $5.20 to $ 65 per tonne of yard waste. Tipping fees reported for MSW composting facilities (both operational and proposed) range from about $26 to $118 per tonne of MSW. The value of any program to compost wastes is greatly increased when an end use for the product is secured; the quantities of wastes requiring landfill are reduced, a beneficial use for the product is found and a revenue is generated from the sale of the compost.

Two communities in Canada are currently composting the organic component of municipal solid waste: Riley, Alberta and Amos, Quebec. Several other municipalities will be initiating pilot programs in the near future.

In the United States, the number of projects for composting sewage sludge has grown substantially since the 1970s. In 1988, there were 115 operational sewage sludge compost facilities. As of 1988, there were five MSW composting facilities in operation in the United States. The States of New Jersey, Minnesota, Wisconsin and Illinois have banned the disposal of leaves in landfills. Private and municipal composting of yard wastes has become very prevalent in many States.

Many countries around the world are using composting to reduce the reliance on landfills. In industrialized countries, composting has gained acceptance principally because it constitutes a means of waste disposal. In developing countries, compost is also valuable in land reclamation and improving soil fertility.

Most policies and standards pertaining to compost facilities, processing and markets have either been recently developed or are in the developmental stages. In Canada, only the provinces of Quebec and Ontario have developed policies specifically for composting operations.

In the United States the Environmental Protection Agency has been active in developing regulations pertaining to sewage sludge products (including compost). State and municipal governments are generally responsible for regulating MSW and yard waste composting.

The Commission of the European Communities has taken the lead in developing policies and guidelines for compost operations in Europe. Individual European countries have also developed compost guidelines, including: France, Austria, The Netherlands, Belgium, Switzerland, the Federal Republic of Germany and Spain. The United Kingdom does not currently have guidelines for limits on heavy metals and other contaminants in MSW compost, but has not accepted the limits proposed by the CEC.

APPENDIX A

LITERATURE SEARCH

The following databases were searched for information relating to composting. Key words were carefully selected to narrow the total number of papers to specific subjects pertaining to the study.

Database	Total Number of Entries	Number of Selected Papers
NTIS	154	100
Enviroline	492	150
Pollution Abstracts	1,066	300
Agricola	1,273	100
Biosis	1,395	50
Embase	175	50
Medline	20	20
	4,575	770

APPENDIX B

PARTIAL LIST OF VENDORS AND FACILITIES*

American Recovery Corporation	Italy	Cassino
		Perugia
Buhler Miag	Belgium	Mons
		Toumai
	Germany	Dusslingen
		Ormesheim
	Great Britain	Isle of Wight
	Italy	Bressanone
	Spain	Barcelona
		Valencia
	Switzerland	Schauffhausen.
	Turkey	Izmir
Daneco	Lebanon	Beirut
	Italy	Ceresara
		Pieve di Coriano
		Tolmezzo
		Termoli
	United Arab Emirates	Dubai
		Fujairah
		Ajman
Dano	Austria	Burgenland
		West Tirol
	Brazil	Sao Paulo
	Egypt	Alexandria
		Ghiza
	France	Parenti
	Great Britain	Anglesea
		Manchester
	Germany	Bad Kreuznach
	Italy	Viareggio
		Pollenza

APPENDIX B

PARTIAL LIST OF VENDORS AND FACILITIES*

	Switzerland	Schaffhausen
Fairfield Service Co.	United States	Wilmington, Delaware
International Process Systems (IPS)	United States	Lebanon, Connecticut
		Fairfield, Connecticut
		Portland, Maine
		Baldwinsville, New York
Recomp	United States	St. Cloud, Minnesota
Taulman	Japan	Iwamisawa City
		Towada
		Abashiri
		Tanko
	Sweden	Fargesta
		Landskrona
	West Germany	Bad Liebenzell
		Bickenbach
		Oberer Karichbach
		Waldmichelbach
		Schlitz
		Erbach

* The above list is not intended to be comprehensive. Individual vendors should be contacted for complete lists of facilities.