EVALUATION OF COMPOSTING FEASIBILITY FOR REGIONAL IMPLEMENTATION

MARK E. LANG, AND RONALD A. JAGER
Dufresne-Henry Consulting Engineers, Inc.
North Springfield, Vermont

ABSTRACT

Composting feasibility studies are performed to identify the solid waste management challenges facing a community, and to evaluate the practicality of implementing the materials processing and composting technologies necessary to meet some of these challenges. The result is a valuable tool which can be used to garner public support and develop the selected alternative. The evaluations described in this paper include the determination of feed material quantities and characteristics, the development of daily material flow diagrams and the evaluation of appropriate technologies. The composting alternatives developed were evaluated using monetary and nonmonetary criteria. Nonmonetary criteria included such factors as mechanical complexity, process control, waste stream compatibility and odor control characteristics.

INTRODUCTION

Municipal officials are facing a formidable task in meeting the challenges imposed by state solid waste management policy and regulation. To implement successful solid waste management plans, municipalities must identify their solid waste management needs, set community goals which comply with state and federal policy, and select processes which are efficient, environmentally sound, and economically viable. This paper summarizes the efforts taken by two regional authorities in New England to meet these challenges. The Franklin County Solid Waste Management District (FCSWMD) Composting Feasibility Study evaluated full municipal solid waste (MSW) composting. The FCSWMD, located in Northwest Massachusetts, consists of 20 member towns with a total population of approximately 65,000.

The Windham Regional Commission Composting Feasibility Study evaluated source separated organic waste composting. The Windham Regional Commission is comprised of 27 member municipalities. The total population of the study area is approximately 44,500.

This paper will identify the way the waste stream to be processed affects the technology selection and unit costs for management of various components of the waste stream. It will also identify some of the benefits and concerns associated with full MSW and source separated organic waste composting.

WASTE STREAM CHARACTERIZATION

The first task in each of the studies was to determine the quantity and characteristics of the waste stream to be managed. This information was used to develop conceptual designs of preprocessing, composting and finish processing systems. In addition, the characteristics of the incoming material was used to estimate the characteristics of the compost product. Table 1 presents the estimated design year quantities of material to be

TABLE 1 WASTE GENERATION RATES

Material	Franklin County (wet tons/day)	Windham Region (wet tons/day)
Municipal solid waste	154	0
Municipal Sludge	142 (@ 20% total solid)	14.5 (@ 20% total solids)
Papermill Sludge	Included in municipal sludge	46.9 (@ 22% total solids)
Septage	Included in municipal sludge	2.2 (@ 18 % total solids)
Food Waste	Included in municipal solid waste	5.2 (@ 20% total solids)
Yard Waste	Included in municipal waste	0.2 (@ 60% total solids)
TOTAL	296	69.0

processed in Franklin County and the Windham Region.

The presentation of the data differs between the two studies. The quantities of food and yard waste generated within Franklin County are included in the value reported for MSW. In addition, paper mill wastewater and septage are co-treated at municipal wastewater treatment facilities, and reported as municipal sludge. Approximately 70% of the sludge generated in Franklin County is the result of paper mill wastewater treatment.

The Windham Region is currently planning to construct a lined landfill to accept their inorganic MSW and a composting facility to process the organic fraction of the MSW stream. The organic fraction of the waste stream targeted by the Commission includes municipal wastewater treatment facility sludge, paper mill sludge, septage, and source separated food and yard waste.

DESCRIPTION OF TECHNOLOGIES

A series of technologies were screened for use in each of the studies. The technologies were divided into three major categories:

(a) Preprocessing.
(b) Composting.
(c) Product finishing.

The technologies evaluated for each category are dependent upon material being processed and the final product objective. This section summarizes the technologies screened within the two studies. Following the screening, alternatives were developed using appropriate technologies and evaluated for use by the District and the Regional Commission.

Preprocessing

Preprocessing consists of unit operations to physically inspect, separate, and prepare the infeed material for the biological or composting phase. Preprocessing may include:

(a) Receiving of infeed materials.
(b) Removal of oversized items.
(c) Removal of recyclables and undesirable materials.
(d) Particle size reduction (may be done in conjunction with mixing).
(e) Mixing of infeed materials to produce a uniform compost feed stock.

Preprocessing facilities require a materials receiving area, consisting of a tip floor and a presort area. Tipping floors should be covered to allow for all-weather operation and enclosed to provide odor containment. It may be desirable to divide the tip floor into different functional areas for the various types of waste received.

Additional preprocessing requirements depend on the type of waste being received. Septage and wastewater treatment facility sludge may require mechanical dewatering prior to composting. Yard waste, consisting of leaves, small diameter brush, and grass clippings may require shredding to improve porosity and expose more surface area to the microorganisms during the composting process.

The characteristics of food waste entering the facility vary widely, depending upon their point of origin. Most food waste contains too much moisture to be handled easily, and requires mixing with other materials to absorb excess water. Shredded yard waste works well for this purpose. Most food waste also requires size reduction prior to initiating the composting process.

MSW requires a significant amount of preprocessing. Oversized items are removed manually, while the waste is on the tip floor to prevent damage to subsequent equipment.

Further inspection and removal of recyclables and undesirable materials is performed prior to entering the composting facility. Recyclables, such as aluminum cans and plastic containers, are removed at hand sort stations. Magnetic separation can be used to remove ferrous materials. Trommel screens, with clear openings of eight or more inches, are often used to remove oversized items prior to entering the hand sorting and magnetic separation areas.

The effect of size reduction of MSW is similar to the effect on food and yard waste. Depending on the technology selected, size reduction may occur as a separate unit process or as part of the mixing process.

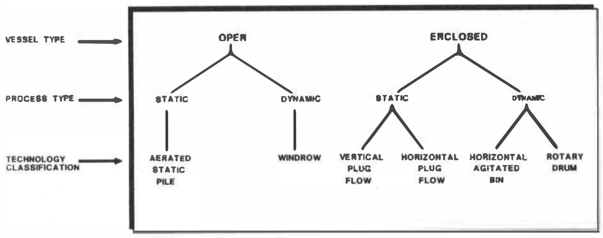

FIG. 1 ORGANIZATION OF TECHNOLOGIES

The importance of thorough mixing prior to entering the composting process cannot be overstated. When composting sludge, septage or food waste, thorough mixing of the waste with an amendment is essential. Amendments, which may consist of sawdust, woodchips or processed yard waste, serve to increase the solids content of the mixture and provide the nutrients required for complete composting. In MSW composting, mixing is required to provide a uniform feed stock to the composting system. Some proprietary composting systems rely on the mixing to initiate the composting process and to provide particle size reduction.

Composting Technologies

There are over 30 proprietary and several nonproprietary composting systems currently in use in the United States. For a feasibility study to meet the goal of building public support, the evaluation of technologies must be thorough and complete. However, subjecting each available technology to a detailed evaluation is complex, time consuming, and not an efficient use of resources. To streamline the evaluation, the technologies were screened prior to developing and evaluating alternatives. The composting technologies can be placed into one of four categories based on the vessel type and mode of operation. The composting systems are either open or enclosed, and operated in either the static or dynamic (mixed) mode. The systems can be categorized further according to the direction of material flow and type of mixing system used. Figure 1 illustrates the organization of technologies used for both studies. Each of the categories illustrated in Fig. 1 is discussed in the following paragraphs.

Aerated Static Pile (Open/Static)

In the aerated static pile composting process the mixture to be composted is placed in a pile over an aeration system. Piles are typically 8–10 ft high, including a 1-ft bed of woodchips which serves as an aeration plenum beneath the pile, and a ½–1-ft layer of finished compost which serves to insulate the pile. The aeration system, which consists of a blower, perforated tubing and the woodchip bed, is used to maintain aerobic conditions, control temperature, and remove moisture.

The material remains unmixed in the pile for the active composting period, which is typically 21 days. After active composting, the pile is broken down using a front-end loader and transferred to a cure pile. Compost remains in the cure pile for an additional 30 days to allow for further stabilization. Static pile composting is a nonproprietary process; however, one vendor, Daneco, uses static pile composting as a part of their MSW composting process.

Windrow (Open/Dynamic)

In the windrow composting process, the mixture to be composted is placed in long parallel windrows. The cross section of the windrows may be trapezoidal or triangular, depending on the type of equipment used for mixing and turning the material. The width of the windrows varies up to 16 ft and the height varies between 3 and 7 ft.

Windrows may be either aerated or nonaerated. In an aerated process, the windrows are constructed over a fixed aeration system. In nonaerated or convectional windrow composting, convective air movement within the windrows is essential for providing oxygen to the microorganisms. Convective air movement is a benefit of the heat produced by the microorganisms, which causes the air to rise, producing a natural draft. Oxygen is also introduced during the turning of the windrows. Windrows are turned more frequently in the conventional windrow process. Windrow composting is a nonproprietary process; however, it is offered as a portion of several vendor supplied systems. Buhler-Miag and Ecological Technologies are examples of vendors who employ the windrow composting process.

Horizontal Plug Flow (Enclosed/Static)

In a horizontal plug flow reactor, the mixture to be composted is placed in one end of a totally enclosed "tunnel" and moved through and out of the reactor by either a hydraulic ram or a live bottom floor. Aeration is provided through a plenum within the vessel floor. Dynatherm, by Compost System Company, and Ashbrook's tunnel reactor are examples of horizontal plug flow composting systems.

Vertical Plug Flow (Enclosed/Static)

In a vertical plug flow system, the materials to be composted are mixed and conveyed to the top of a vessel. The mixture moves down through the vessel when the lowest layer is removed. Composting occurs as the material travels from the top of the bin to the bottom. Aeration is provided either through horizontal plenums or vertical air lances within the vessel. American-Biotech and Taulman are examples of vertical plug flow composting systems.

Horizontal Agitated Bin (Enclosed/Dynamic)

In the horizontal agitated bin process, the mixture is loaded in long rectangular concrete bins. Each bin is open at the top, but sheltered within a building. An agitator/mixer, which consists of a rotary toothed drum and conveyor, travels on rails on top of the bin walls. The daily operation of the agitator/mixer moves the material down the length of the bin, which makes space available to load new material in the bin each day. A series of aeration zones along the length of the bins maintains aerobic conditions, removes moisture, and controls temperature.

Paygro by Compost Systems Company, Royer, and International Process Systems (IPS) are examples of rectangular horizontal agitated bin systems. The Wendilen Composting System, developed by Buhler, Inc., is similar in operation and is categorized as a horizontal agitated bin technology. The Wendilen system consists of one large horizontal bin which is mixed once each week. The Fairfield system, by Compost System Company, is an example of a circular agitated bin. This system employs a series of augers attached to a travelling bridge to agitate and convey the composting material.

Rotary Drum (Enclosed/Dynamic)

A number of MSW composting facilities include a rotary drum ahead of the composting technology to enhance mixing and initiate composting. Material is loaded in one end of a large, slowly rotating drum, where it is continually agitated for a period of 8 hr to 5 days, depending on the manufacturer. The tumbling motion serves to reduce the particle size of the material to be composted. Following the drum, the composting process is completed in either a windrow or horizontal agitated bin system. Examples of rotary drum systems include Bedminster Bioconversion, RECOMP, and Riedel Waste Disposal Systems. Buhler Inc. uses a drum mixer with a relatively short detention time for feed conditioning prior to either their windrow or Wendilen composting process.

Product Finishing

The success of a composting facility rests on its ability to produce a consistent high quality product. Product finishing equipment is used to condition compost to meet local market standards. Typical product finishing equipment includes fine screening, with clear openings of ¾ in. or less, destoning and grinding or delumping. The equipment to be employed is dependent upon the anticipated use of products.

MARKET SURVEY

To estimate demand for compost and the degree of product finishing required, a market survey was conducted as part of each study. Typical compost markets include nurseries, contractors, loam production, land reclamation, professional groundskeepers, highway departments, and landfills. For each potential market, local information on the quantity of similar material currently used, interest in using compost to supplement or replace products currently used, and product specification requirements must be determined. In each study the importance of considering composting as a manufacturing process, rather than a waste disposal practice, was stressed. Typical concerns among potential large volume compost users include the consistency of the product and the reliability of product data, such as metal content and pH. The results of the marketing surveys indicate that there is an interest in using compost. The majority of potential users contacted indicated they would require an initial test period of compost use and an assurance of product consistency prior to entering into any long-term agreement. To establish a market for compost product will require the development of an aggressive marketing program.

ALTERNATIVES DEVELOPMENT AND EVALUATION

The technologies selected following the screening process were used to develop composting alternatives. Each alternative was subjected to an evaluation procedure designed to provide an objective review of the system. The alternatives were evaluated using monetary and nonmonetary criteria. As part of the monetary analysis, preliminary design criteria and floor plans were developed for each alternative. The preliminary designs were used to estimate the facility's capital costs.

Operations and maintenance costs, including labor, materials, and power were also estimated for each alternative.

To complete the evaluation, each alternative was subjected to the following nonmonetary criteria.

(a) Waste stream compatibility.
(b) Reliability/mechanical complexity.
(c) Operational complexity/process control.
(d) Expandability.
(e) Land area requirement.
(f) Odor potential.
(g) Product marketability.

FINDINGS AND RECOMMENDATIONS

The following sections summarize the evaluation of alternatives for each study and present the recommended management plans.

Franklin County Solid Waste Management District

Daily Material Flow

The recommended MSW composting alternative consists of rotary drum preprocessing followed by horizontal agitated bin composting. The anticipated daily material flow for the recommended alternative is presented in Fig. 2. The diagram includes initial diversion of recyclables, yard waste and oversized material. In Franklin County, yard waste will be composted separately using a conventional windrow.

Technology Selection

The detailed evaluation of alternatives resulted in the conclusion that odor control, operational complexity/process control, and end product quality, not cost, were the most significant evaluation criteria. While the cost of implementation is always a primary concern, the present worth cost analysis of the alternatives resulted in an overall range of approximately 20% between the lowest cost and highest cost alternatives. At this level of planning it was felt that the cost of an alternative could not be used as the primary evaluation criterion.

A key item identified as affecting odor control, operational complexity/process control, and end product quality is the ability to mix the material during the composting process. The advantages of dynamic over static systems include the ability to correct inadequate mixing of the infeed material, the elimination of large clumps, and the prevention of compaction of composting materials.

The second item identified as having an affect on end product quality was preprocessing. Systems which rely on a high degree of materials separation with hand sorting stations and ferrous separation were preferred to processes which shred the entire MSW stream. Shredding of the entire MSW stream can result in an end product which is contaminated with foreign objects such as glass, metal, and plastic. At the same time, it was realized that particle size reduction of the organic fraction of the MSW stream was essential to a successful composting operation.

The evaluation of alternatives was based on the application of these three key factors as well as criteria such as mechanical reliability, expandability and land area requirements. A summary of the advantages and disadvantages identified for each alternative are presented below:

Aerated Static Pile Composting

Advantages:
(a) Moderate capital and operating costs.
(b) Mechanically simple and reliable.
(c) Readily expandable.

Disadvantages:
(a) High odor potential.
(b) Poor odor containment characteristics.
(c) Large land area requirements.
(d) Limited process control.

Windrow Composting

Advantages:
(a) Moderate capital and operating costs.
(b) Mechanically simple and reliable.
(c) Improved process control.
(d) Low odor generation potential.
(e) Readily expandable.
(f) Capable of producing consistently high quality product.

Disadvantages:
(a) Large land area requirements.
(b) Poor odor containment characteristics.
(c) Large odor treatment systems required.

Horizontal Agitated Bin

Advantages:
(a) Moderate capital and operating costs.
(b) Mechanically simple and reliable.
(c) Readily expandable.
(d) Excellent process control.
(e) Low odor generation potential and good odor containment characteristics.
(f) Relatively small land area requirements.
(g) Capable of producing consistently high quality product.

Disadvantages:

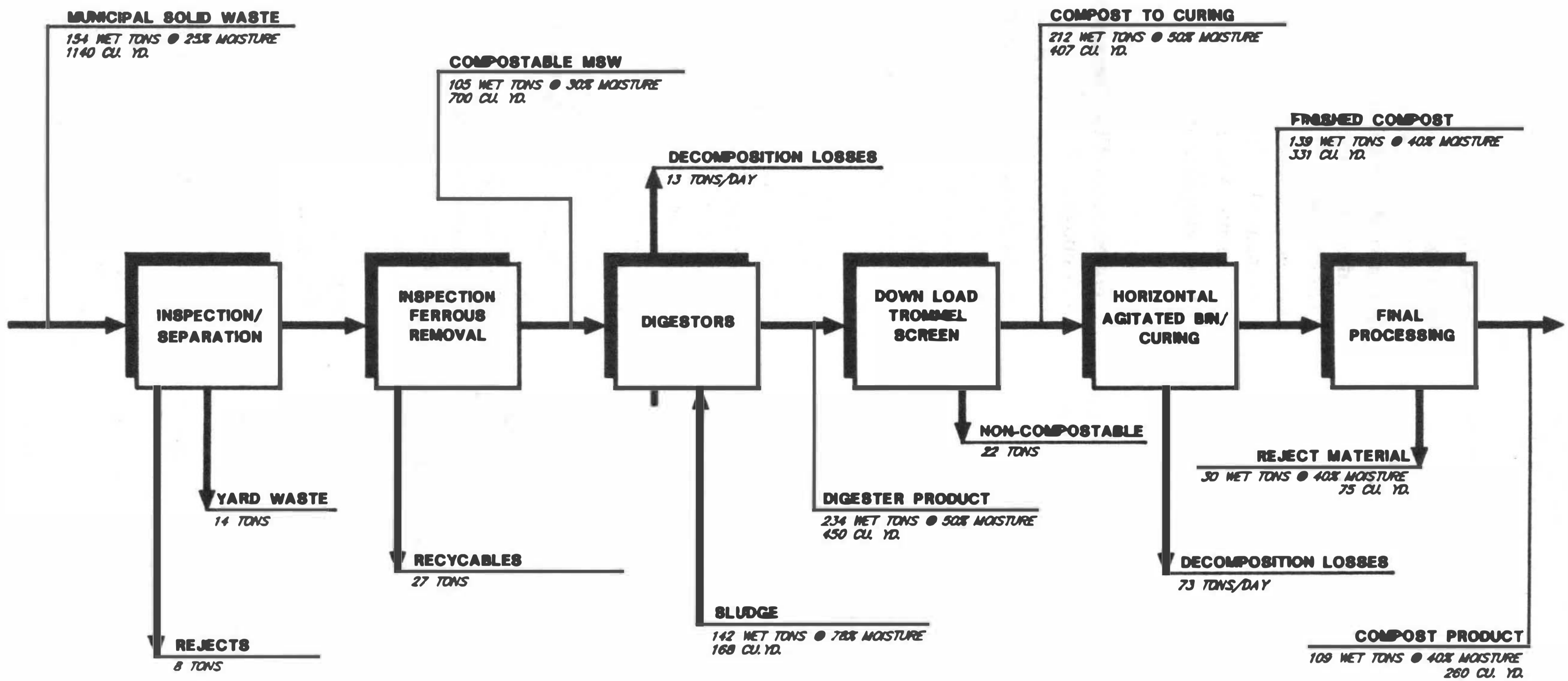

FIG. 2 FRANKLIN COUNTY SOLID WASTE MANAGEMENT DISTRICT RECOMMENDED PLAN
(Material Flow Diagram)

(a) Process air is discharged directly into the building, resulting in an uncomfortable working environment and corrosion of structures and equipment.

(b) Moderate to large odor treatment systems required.

Rotary Drum/Horizontal Agitated Bin Composting

Advantages:

(a) Increased process control.

(b) Capable of producing a very high quality product.

(c) Decreased preprocessing requirements.

(d) Enhanced mixing prior to HAB composting.

Disadvantages:

(a) Moderately high capital cost.

(b) Equipment is large, requiring specialized procedures for installation and repair.

(c) Poor expansion capabilities beyond the capacity of the digesters.

Summary of Evaluation

The evaluation identified horizontal agitated bin as the preferred composting technology. The rectangular bin configuration was recommended over the circular because of its mechanical simplicity and higher degree of duplicity. The advantages of particle size reduction without shredding were also recognized. Because of this it was recommended that the horizontal agitated bin composting process be preceded by a rotary drum.

Recommended Plan

Figure 3 presents the conceptual layout for the recommended alternative. MSW will be deposited on a totally enclosed tip floor. Oversized and reject material will be separated by hand and the remaining material will be loaded in a live bottom bin with a front-end loader. MSW will then pass through a hand sort station to remove recyclables, uncompostable material, and a ferrous separator for metals removal. Dewatered sludge will be deposited in a separate live bottom bin, also within a totally enclosed tip floor. The sludge will be conveyed directly to the rotary drums.

The preprocessed MSW will also be fed into the two rotary drum digesters, where mixing and size reduction will occur under aerobic conditions. This mixture will then be fed to a download trommel screen, with clear openings of approximately 3 in. to remove particles too large to compost. The product of the download trommel screen is then transferred to the horizontal agitated bin composting system with front-end loaders. Following the active composting period of 21 days, the material will be transferred to the curing area. The final product will be screened using a ½-in. trommel screen, ground to break up clumps, and run through a destoner.

The estimated capital cost for the Franklin County Facility, including the enclosure of all processing areas within a pre-engineered metal building and odor control using a biofilter, is approximately 11 million dollars. Operations and maintenance costs, including reject disposal, at $70/ton, are estimated to be 1.6 million dollars/year, for a total equivalent uniform annual cost of 2.8 million dollars. Equivalent uniform annual costs were calculated using a 20-year planning period and 9% interest rate. This equates to a unit cost of $30/ton of MSW delivered.

Windham Regional Commission

Daily Material Flow

Figure 4 presents the anticipated daily material flow diagram for the recommended organic waste composting alternative, horizontal agitated bin, within the Windham Region. As with full MSW composting, the daily material flow is dependent on the type of composting system employed. Figure 4 is representative of either windrow or horizontal agitated bin composting alternatives.

A major focus of the evaluation was to determine the feasibility of composting paper mill sludge with the organic waste generated in the region. While the inclusion of paper mill sludge was determined to be feasible, the final recommendation was to exclude papermill sludge from the initial facility design due to the unwillingness of local mills to make long-term commitments. Figure 4 presents the material flow diagram for the recommended organic waste management plan, without papermill sludge.

Technology Selection

In the Windham Region the primary markets identified were for turf establishment and landscape contractors. Nurseries, which typically require the highest quality product, were not identified as a significant potential market. Preprocessing and finish processing technologies were selected accordingly. In addition, all wastes received at the facility will be source separated, reducing the degree of uncompostable material contained in the infeed material.

The application of the evaluation criteria in the Windham Region was similar to that described for MSW composting in Franklin County. The primary difference in the evaluation process centered on waste stream compatibility. This criterion evaluated each technology's ability to compost sludge, septage, and various components of the MSW stream.

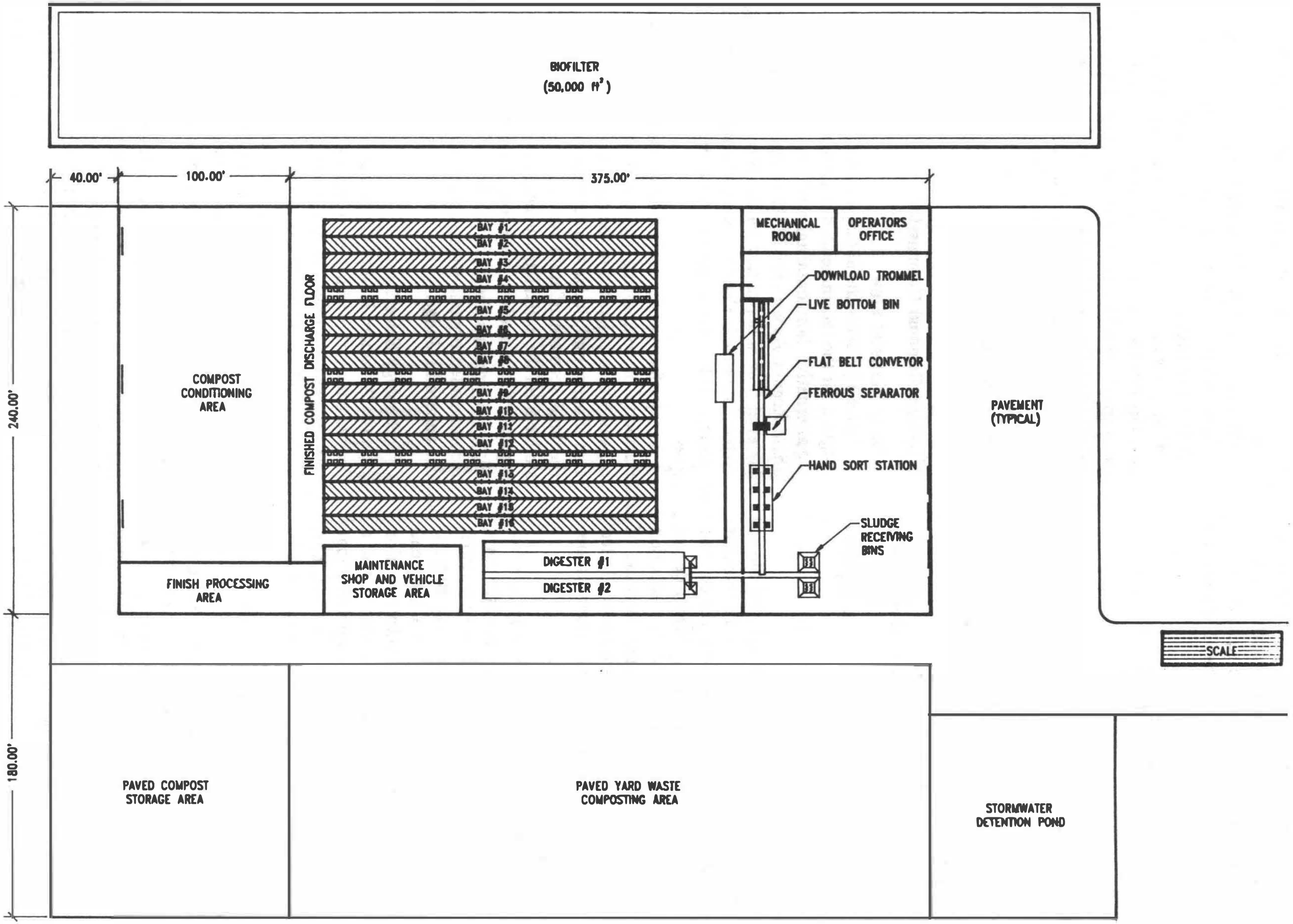

FIG. 3 FRANKLIN COUNTY SOLID WASTE MANAGEMENT DISTRICT
(Recommended Facility Site Plan)

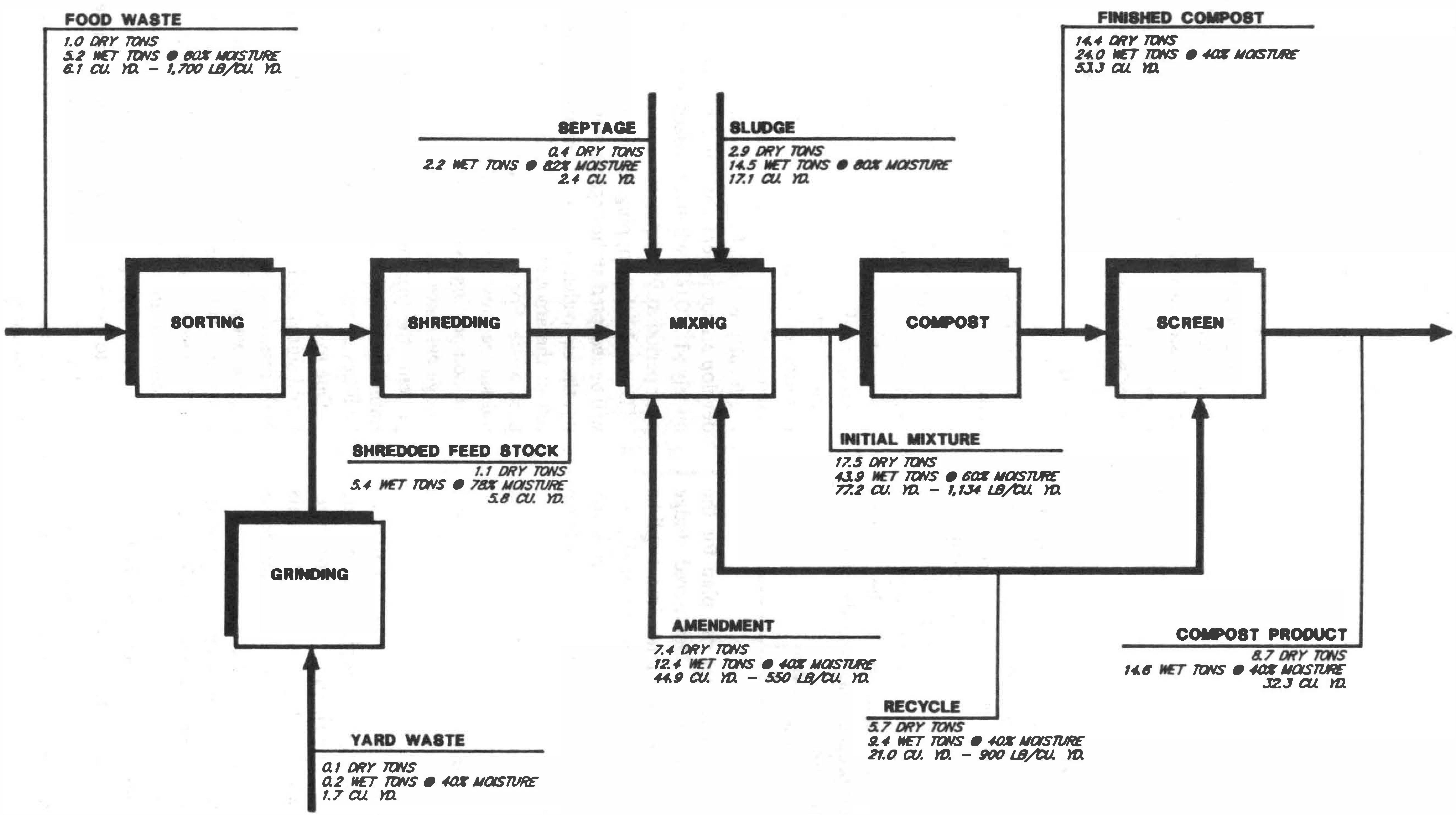

FIG. 4 WINDHAM REGIONAL COMMISSION RECOMMENDED PLAN
(Material Flow Diagram)

TABLE 2 WINDHAM REGIONAL COMMISSION ORGANIC WASTE MANAGEMENT FACILITY PROPOSED TIPPING FEE STRUCTURE

Material	Unit Cost			Quantity	Annual Revenue
	($/dry ton)	($/wet ton)	($/gal)	(dry tons/day)	($/year)
Dewatered Sludge	$622	$124		2.3	$522,200
Liquid Sludge	$1,419	$35	$0.15	0.8	$414,300
Septage	$1,659	$25	$0.10	0.40	$242,200
Food Waste	$898	$180		1.00	$327,800
Yard Waste	$276	$166		0.10	$10,100
Total				4.6	$1,517,000

Summary of Evaluation

The results of the evaluation identified rectangular horizontal agitated bin as the preferred composting technology. Horizontal agitated bin was selected due to its low building area requirements when compared to other dynamic composition systems, high degree of process control, and ability to consistently produce a high quality end product. Agitation of the material during the composting process was considered to be a key factor in the evaluation.

Recommended Plan

Figure 5 presents the conceptual site plan for the organic waste composting facility. Dewatered sludge and septage, recycled product, and amendment will be deposited on the compost facility portion of the enclosed tip floor. Yard waste will be ground in a tub grinder on a paved area adjacent to the food waste tip floor. Ground yard waste will either be stored in the covered amendment storage area or deposited directly on the food waste tipping floor.

Food waste will be deposited on top of the ground yard waste. The yard waste will absorb excess water in the food waste to avoid puddling and subsequent odor and nuisance problems. The food waste will then be hand sorted to remove large or inorganic objects and loaded into a shredder. The shredder functions to reduce the particle size of the food waste and to mix the food and yard waste. The shredder will discharge directly to the compost facility tip floor.

Septage will be delivered to the composting facility by private haulers and stored in an equalization tank. This tank will allow haulers to discharge septage when the dewatering facilities are not operating. The tank will also provide flow equalization during the spring and fall, when peak septage loadings are experienced. Septage will be screened prior to dewatering with municipal sludge.

Municipal sludge will be delivered in either a liquid or dewatered form. Two of the wastewater treatment facilities in the region have dewatering capabilities. Liquid sludge, from the remaining facilities in the region will be stored at the facility in a second equalization tank.

Liquid sludge and septage will be dewatered with two 1-m belt filter presses. Dewatered cake from each press will be transferred to the compost tipping floor.

Dewatered sludge and septage, processed food and yard waste, amendment and recycled compost will be deposited in one of two batch pugmill mixers. Each mixer will be equipped with a scale to allow the operator to obtain the proper ratio of organic wastes and amendments. After batch mixing, the infeed material is transferred to the horizontal agitated bin composting system by means of a skid steer loader. Following the active composting period of 21 days, the compost will be placed in a covered product conditioning area for curing. A trommel screen will remove any oversize particles prior to distribution.

The estimated capital cost for the organic waste composting facility, including enclosure of all processing areas within a pre-engineered metal building and biofiltration of all exhaust air, is $7 million. The anticipated annual operation and maintenance expense for the facility is $900,000, these estimates were used to develop an equivalent uniform annual cost of approximately $1,700,000 when amortized over a 20-year planning period at 9% interest.

To establish a tipping fee for each material which will be accepted at the organic waste management facility, the equivalent uniform annual cost was prorated to reflect the amount of materials handling required for each waste. For example, those facilities delivering liquid sludge must be charged the expense of dewatering and composting while those delivering a dewatered sludge cake are only charged for composting. Table 2 presents the proposed tipping fee structure based on implementation of the full organic waste management facilities as previously described.

Due to the high costs associated with implementing liquid sludge and septage dewatering and uncertainties with regard to actual quantities of source separated organic waste which will be collected, the final recommendation is to implement the organic waste composting facility in phases. The first phase will be designed to compost an average of 2.7 dry tons of dewatered sludge and septage. The capital cost of phase 1 is estimated to be $3,000,000. Subsequent phases will be added to accommodate liquid sludge and food waste once organic waste quantities are verified and site specific cost estimates are refined.

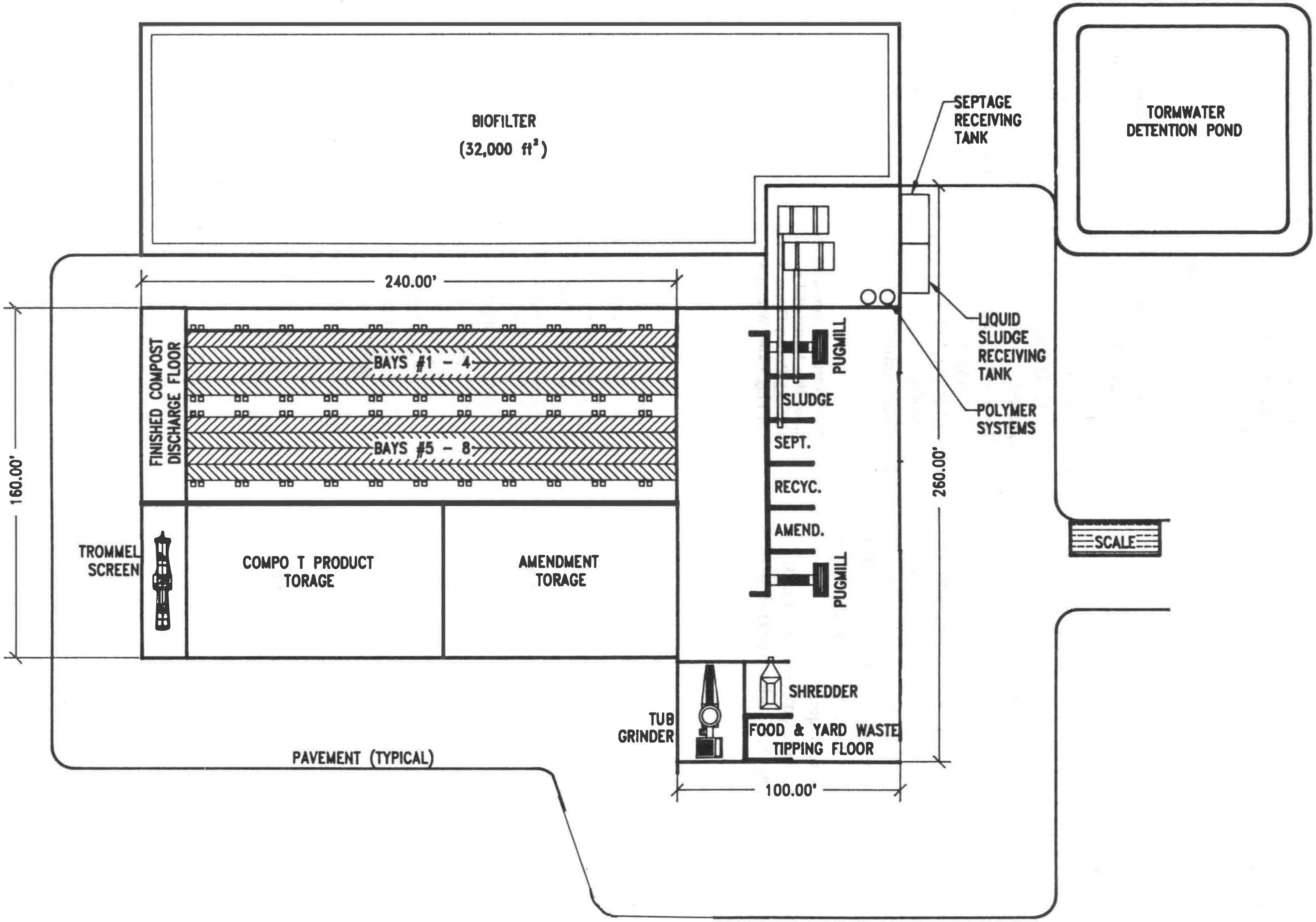

FIG. 5 WINDHAM REGIONAL COMMISSION
(Recommended Facility Site Plan)

Conclusion

Each feasibility study identified a composting system which can be designed to meet the solid waste management goals for each region in an environmentally sound and effective manner. Key factors identified in each study were process control, odor control, and the ability to consistently produce a high quality product. As a result the central recommendation in each study is to implement the horizontal agitated bin composting technology. This technology was selected based upon its ability to agitate the mixture during the composting process. It is felt that daily mixing will minimize odor generation and contribute to high product quality.

Due to the heterogenous nature of MSW, the recommendation in Franklin County included a significant degree of preprocessing, including several materials separation steps. It is felt that the high degree of materials separation, with approximately 50% of the MSW feedstock diverted to either incineration or landfilling, is necessary to ensure product quality.

In Windham the basic unit cost for organic waste preprocessing, composting and odor control is estimated to be in excess of $130 per wet ton, $900 per dry ton. A large component of that cost is associated with the equipment and labor required to prepare the incoming material for composting. The processing includes sludge and septage dewatering, along with food and yard waste size reduction.

The Windham Feasibility Study also identified the economy of scale associated with this type of a composting system. Comparing costs of composting with and without paper mill sludge indicates that increasing the amount of sludge to be composted decreases the unit cost. Using the information generated as part of the present worth analysis indicates that increasing the facility's total capacity from approximately five dry tons per day to 21 dry tons per day will reduce the present worth unit cost by over 50%. This provides the commission an impetus to generate interest in their proposed composting program.

Key Words: Composting; Food Waste; Horizontal Agitated Bin; Horizontal Plug Flow; Municipal Solid Waste (MSW); Rotary Drum; Septage; Sludge; Static Pile; Vertical Plug Flow; Windrow; Yard Waste