POTENTIAL FOR COMPOSTING RESIDUE GENERATED FROM REFUSE DERIVED FUEL PREPARATION

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ABSTRACT

The Connecticut Resources Recovery Authority's ("CRRA") Mid-Connecticut Waste-to-Energy Facility produces approximately 1200 ton/week of organic type residue from its refuse derived fuel processing Facility. This material is currently landfilled along with nonprocessible waste received at the Facility. CRRA with a partial grant from the Office of Policy Management of the State of Connecticut commissioned a pilot test and economic study to determine if this residue could be composted to a viable product. R. W. Beck and Associates, in conjunction with E&A Environmental Associates conducted the study for CRRA. The study consisted of composting a sample of residue during a 77 day composting and curing period, the development of a design basis and a conceptual design and engineering feasibility analysis. This paper presents the results of the pilot study and the subsequent feasibility analysis.

INTRODUCTION

The Connecticut Resources Recovery Authority ("CRRA") currently processes approximately 2000 ton/day of municipal solid waste ("MSW") into refuse derived fuel ("RDF") at the Mid-Connecticut Facility in Hartford. The RDF is subsequently combusted to ultimately produce electricity. One of the objectives of the process is the removal of inert material and wet, low Btu content portion of the waste stream. This portion is removed by passing coarsely shredded MSW through a ¾-in. trommel screen. The resulting under sized fraction ("RDFU") amounts to approximately 10% of the input MSW or 200 ton/day. This residue is currently landfilled at the CRRA's Hartford landfill. Composting has been proposed as an alternative method of disposal, which would allow utilization of the RDFU and the subsequent diversion of this material from the landfill. As described in this paper, the RDFU was successfully composted in a pilot test and the process is projected to be economically feasible when the compost is used as a landfill cover.

The composting process entails the rapid decomposition of an organic waste material to a nonodorous, biologically stable soil amendment with a variety of end uses. End usage of a compost product ranges from a low value use as landfill cover to high value horticultural uses. End use is ultimately dependent on product quality and markets.

METHODOLOGY OF THE PILOT TEST

The Composting and Curing Process

The composting phase was conducted with the International Process System ("IPS") horizontal agitated bed system.

TABLE 1 CRRA COMPOSTING PILOT MASS BALANCE — INITIAL MIXTURE REFUSE DERIVED FUEL UNDERS (RDFU)

Date Delivered	Material	Wet Weight Pounds	Total Solids Percent	Volatile Solids Percent (1)	Dry Weight Pounds	Bulk Density Lbs/Yd3	Volume Yd3
1/7	RDFU (as is)	24,380	67.68	43.67	16,500	1,131	21.58
1/7	RDFU (+H_2O)	25,214	64.67		16,500	1,223	20.86
1/8	RDFU (as is)	30,020	66.34	43.67	19,915	1,100	27.29
1/8	RDFU (+H_2O)	31,732	62.76		19,915	1,252	23.35
	Final Mix	57,246	63.61	43.67	36,415	At 1,200	47.71
						At 1,400	40.89

(1) Dry Basis

The IPS's composting system at the Earthgro composting facility consists of a series of bays with width, height and length dimensions of 6.5 by 5 ft by 220 ft respectively. The system entails a continuous feed process whereby 14 cubic yards of input mix are added to each bay 5 days/week. An automatic agitator/mixer passes through each bay daily moving the composting mass forward 12 ft towards the discharge end. The agitator also mixes and breaks up the material. The process retention time is 21 days.

Temperature control and aerobic conditions are maintained by an aeration system at the base of each bay. The aeration system consists of a series of five blowers with a capacity of 600 cu ft/min ("CFM") at a 6-in. pressure drop. Each blower provides air to a 44-ft section of the bay. Air is distributed by a header connected to a nest of four perforated pipes. Aeration pipes are embedded in washed stone which further enhances air distribution. The flow of air through the composting mass is controlled by a timer which allows blower operation for a preset time period.

Water Addition

The mass balance (Table 1) presents the amount of RDFU composted in the pilot study and the amount of water added to the RDFU. The high solids content of the RDFU necessitated the addition of water. For most organic materials, the optimal solids content entering the composting process is in the range of 40–45%. The RDFU contained a significant portion of nonabsorbent biologically inert refuse material such as glass grit and plastic, effectively decreasing the optimal moisture content for composting.

Aeration

For the RDFU, the ventilation blowers were initially set to provide aeration for two minutes every 10 min. This schedule was changed on day three to 1 min of operation every 10 min. After 8 days of composting, aeration was further reduced to a setting of 2 min of operation every 30 min. This level of aeration was maintained throughout the duration of the composting phase.

Curing Phase

After completion of the 21-day composting phase, composted RDFU was removed from the IPS system with a minimal amount of cross contamination. The compost was transported to the Hartford landfill and placed in conical curing piles. The RDFU curing pile was approximately 35 cu yd and was turned three times weekly with a front-end loader to provide some aeration.

Process Monitoring and Analyses

Temperature

During the composting phase, a 36-in. length dial thermometer was used to determine temperatures at a 2-ft depth. The temperature performance of each load was monitored by gathering temperature data at 12-ft intervals along the length of the composting mass. In the curing phase, temperatures were taken three times a week, at three equidistant points 4 ft high on the conical curing piles at a depth of 3 ft.

Sampling and Analyses

Other process control parameters that were analyzed included: bulk density, total solids, volatile solids, carbon dioxide respiration rate, (performed by E&A Environmental Consultants) ("E&A") and pH, total kjeldahl nitrogen, (performed by the Connecticut Agricultural Experiment Station).

Samples, during the composting phase, were taken from the top of the composting bay at a depth of 1 ft. For each of the two materials composted, three sets of samples were taken at 16-ft intervals. During the curing phase three replicate samples were taken from each cure pile at a depth of 1 ft at the same point where temperatures were taken.

In addition to the process control parameters, the input material was analyzed for the following nutrient and contaminant parameters.

(a) Nutrients—P, K, Ca, and Mg.

(b) Soluble salt concentration.

(c) Heavy metals—Cu, Zn, Ni, Pb, Cd, Cr, Hg, As, Se, and Mo.

(d) Total chromatographable hydrocarbons.

The final product was also tested for:

(a) TCLP metals.

(b) Volatile organic compounds.

(c) Fecal coliform, fecal streptococci, and salmonella species.

Testing Methodology

All metal and organic contaminant analyses were conducted according to EPA methods. Plant nutrients and pH were conducted according to methods described by the American Organization of Analytical Chemists, and American Public Health Association methods were used to determine the presence of Salmonella species and the populations of fecal indicator organisms.

Respiration

The application of CO_2 respiration rate to determine compost stability is a relatively new analytical technique. For this work, the method of Bartha and Pramer (1965) [1] was used to determine carbon dioxide respiration rate of compost samples. This method has frequently been used to monitor the decomposition process in both soils and composts. We believe that the application of this method for determining compost stability is valid.

Respiration data (see Fig. 2) is expressed as mg CO_2 carbon evolved per gram of compost carbon. Values for compost carbon are based on the volatile solids content divided by a constant of 1.8 [2]. The results are expressed in terms of compost carbon in order to provide a sense of how available the remaining compost carbon is for microbial growth. High respiratory activity indicates transformation of the compost carbon to carbon dioxide and carbon compounds such as humic acids is incomplete. A low respiratory activity indicates that the remaining compost carbon is in a refractory, unavailable form for microbial growth and the organic waste is sufficiently stabilized for agronomic use.

A tentative compost stability index has been developed based on ongoing research conducted by E&A. This index was determined by examining the respiration rate of a variety of waste materials and compost products (Table 2).

PILOT STUDY RESULTS

Process Monitoring Parameters

Temperature

Temperature monitoring results indicate that the RDFU required a longer period of time to achieve thermophilic temperatures than that observed at MSW composting facilities. Previous MSW composting experiences have indicated that a temperature of 55°C is reached within a week after initiation of composting. In a previous pilot study conducted by E&A in Crow Wing County, Minnesota, Process to Further Reduce Pathogens ("PFRP") pathogen reduction requirements were met after a one week composting period in each of seven aerated static piles. A survey of several currently operating composting facilities also indicates thermophilic temperatures are rapidly achieved during MSW composting. For example, thermophilic temperatures are achieved after a three or four day period at the Portland, Oregon MSW composting facility.

A review of the composting phase temperature profiles for RDFU (Fig. 1) indicates the RDFU required a period of approximately 8 days to reach 45°C. A temperature of 45°C is considered to be the lower boundary of the thermophilic temperature range. Additionally, a closer examination of Fig. 1 indicates the RDFU temperatures slowly declined after reaching a peak on the eighth day.

The compost pile temperatures observed during the curing phase were substantially higher than temperatures observed during the composting phase. Temperatures in the RDFU cure pile were in the 50–60°C range over the last 30 days of the curing phase.

The achievement and maintenance of thermophilic temperatures during composting are of importance for process efficiency and pathogen destruction. Research conducted on sewage sludge indicates the optimal temperature range is between 50°C and 60°C [3,4]. The optimum temperature for composting high cellulose

TABLE 2 TENTATIVE COMPOST STABILITY INDEX

Respiration Rate mgCO_2-C/g compost carbon*day	Stability Rating	Characteristics	
<1	Very stable compost	o Well cured compost o No odors or phytotoxicity	o Fine "soil like" texture o High humic acid content o No negative impact on plant growth at high application rates
1 - 3	Stable compost	o Cured compost o Limited odor and phytotoxicity potential	o Minimal impact on soil carbon and nitrogen dynamics o Moderate humic acid content o May be used for growing established plants and plants from seeds at high application rates
3 - 10	Moderately unstable compost	o Uncured compost o May be used for growing established plants if diluted properly o Minimal odor production	o Addition to soil may result in nitrogen o High phytotoxicity potential o Not recommend for growing plants from seeds
10 - 20	Unstable compost	o Very immature composts or moderately stabilized waste materials (i.e. digested sewage sludge)	o High odor and phytotoxicity potential
>20	Unstabilized waste	o Very reactive when applied to soil	o Extremely odorous and phytotoxic

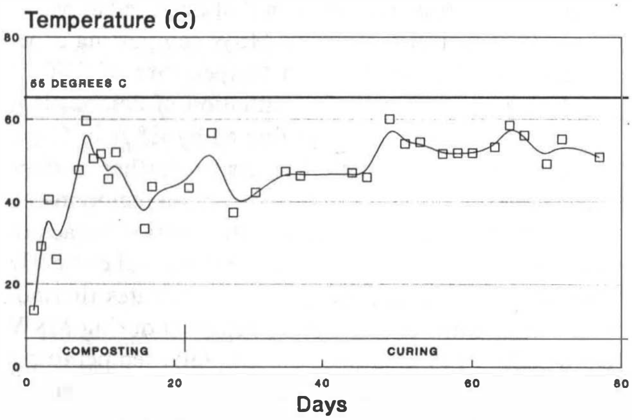

FIG. 1 COMPOSTING TEMPERATURES RDFU

wastes such as MSW has yet to be firmly established. However, laboratory research indicates the optimal temperature for cellulose degradation is in a range of 55–65°C [5], suggesting the optimum temperature for composting MSW may be higher than the temperature optimum for sewage sludge.

The destruction of human pathogens as a result of thermophilic temperatures obtained during the composting of sewage sludge is well documented [6]. Based on this body of research, regulations have been implemented that require specific temperature requirements to be met in order for a sewage sludge product to be beneficially utilized (40 CFR part 257). The pathogen reduction requirements are referred to as Process to Significantly Reduce Pathogens ("PSRP") and PFRP.

For composting, PSRP requirements entail the maintenance of 40°C for 5 days. Additionally, 55°C must be maintained for a 4-hr period. The more stringent PFRP requirements entail the maintenance of a minimum temperature of 55°C for three consecutive days, in a static pile or approved in-vessel system. In a turned windrow system, 55°C must be maintained for a 15-day period.

With respect to the present pilot study, the RDFU failed to meet PFRP pathogen reduction requirements, PSRP pathogen reduction requirements however were achieved. The inability of the RDFU to achieve 55°C during the composting phase appears to be a result of the following factors:

(a) Excessive aeration of the composting mass.

(b) Low ambient temperatures.

(c) Low microbial availability of carbon in the RDFU.

The objective of aeration is to provide oxygen for the respiring microbial biomass and remove excessive heat resulting from microbial respiration. In a composting system, aeration rates need to be sufficient to provide an adequate supply of oxygen for microbial growth. Correspondingly, the aeration rate should not exceed a level whereby the rate of heat removal results in a failure to meet pathogen reduction requirements and does not allow optimum process temperatures to be obtained. The temperature profiles of the RDFU indicate aeration rates during the composting phase were excessive. This conclusion is supported by the higher temperatures observed during the curing phase where tri-weekly turning obviously removed less heat than the daily turning and forced aeration provided in the composting phase.

During the composting phase, aeration was provided to the RDFU 20% of the time for the first 3 days. At this point the operation of the blowers was decreased to 10%. After 8 days the blower operation was decreased from 10% to 6.8%. This aeration rate was maintained for the duration of the composting phase. The reduction in aeration rates was initiated in an attempt to increase compost temperatures. Despite lowering the aeration rates supplied to the RDFU, PFRP pathogen reduction requirements were not achieved. Temperatures observed during the curing phase suggest a further decrease in the aeration rate during the composting phase may have resulted in the achievement of thermophilic temperatures. However, as aeration rates are further reduced, a sufficient level of oxygen may not have been supplied.

A second factor affecting the development of thermophilic temperatures during the composting phase of the pilot study, was the low ambient temperature. During the composting phase, ambient temperatures ranged from −5°C to −10°C. Typically during winter months, aeration rates need to be further reduced as the passage of cold air through the composting mass has a substantial impact on pile temperature. With respect to the impact of ambient air temperatures on the composting process, this pilot study represents a worst case scenario.

A third factor affecting heat production may be the low volatile solids content of the RDFU and the high cellulose content of the volatile solids fraction of the RDFU during the composting phase. The initial volatile solids content of the RDFU was 43.7%. This indicates approximately one half of the feedstock was inorganic material. The volatile solids content of an MSW composting feedstock is substantially higher, ranging from approximately 65% to 75%. Additionally, a high proportion of the RDFU consists of paper products, a highly cellulosic material. Cellulose carbon is much less available for microbial activity than the carbon contained in starches, sugars, proteins and fats [7]. As a consequence of the low volatile solids content of the RDFU and the high cellulose content of the volatile solids, microbial activity during the composting phase may have been limited, thereby resulting in a relatively low heat output.

Moisture Content

During the composting and curing phase, the moisture content of the RDFU did not change appreciably. The initial moisture content (35.3%) was very close to the final moisture content (36.7%).

The optimal moisture content for composting organic materials is most commonly in the 40–60% range. The moisture content of the RDFU as it is produced is in the 35% range, suggesting the need for additional water. However, the pilot study results indicate moisture was sufficient for composting to occur. This observation is most likely a result of the high glass and plastic content of the RDFU. For example, assuming the RDFU consist of 20% glass and plastic on a dry weight basis, removal of this biologically inert fraction results in an organic fraction with a moisture content of approximately 40%. These calculations suggest a minimal moisture content of 35% should be maintained during composting of this material.

Volatile Solids

The volatile solids fraction is also referred to as organic matter. The reduction in volatile solids observed during composting is a result of organic carbon being mineralized to carbon dioxide and consequently removed from the system. With respect to the pilot study the volatile solids fraction also includes plastics and other combustible polymers which is refractory with respect to composting. Nonetheless, the reduction in volatile solids observed over the duration of the pilot study represents the evolution of carbon dioxide as a result of microbial activity. Over the duration of the pilot study, the volatile solids of the RDFU were noted to decline from 43.7% to 38.4%.

Carbon Dioxide Respiration Rate

Determination of the CO_2 respiration rate is a means of monitoring the composting process. Carbon dioxide is evolved as a result of the microbial decomposition of organic substrates. The rate of CO_2 evolution is highest during the early stages of the composting process. As readily available carbon substrates become utilized, the respiration rate decreases. The CO_2 respiration rate can be used to determine the degree of decomposition or stability of a compost sample.

Stability is of relevance to the composting process as an unstabilized material may be odorous and have a negative impact on plant growth. Additionally, the increased processing time required to sufficiently stabilize a compost can add substantial capital expense to a composting facility. An unstabilized compost may have a negative effect on plant growth as a result of phytotoxic compounds, a high biological oxygen demand and/or the immobilization of inorganic nitrogen when applied to soil.

The CO_2 respiration rates of the RDFU, determined at several points throughout the study, is presented in

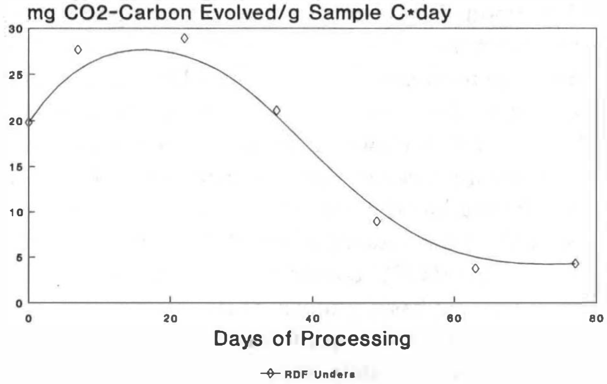

FIG. 2 CARBON DIOXIDE COMPOST RESPIRATION RATES

TABLE 3 NUTRIENT AND METAL ANALYSES OF COMPOSTED RDFU SAMPLED ON DAY 77

Nutrient Content (%)

	N	P	K	Ca	Mg	pH
RDFU	1.09	0.94	1.11	3.74	0.73	8.6

Metal Content (ppm) (1)

	As	Cd	Cr	Cu	Hg	Mo	Ni	Pb	Se	Zn
RDFU	1.5	4.3	280	527	<10	31	249	686	<5.0	713

Fig. 2. The respiratory activity is noted to be in the 20-mg CO_2–carbon respired per g of compost carbon (referred to hereafter as mg) range during the composting phase. After approximately a 45-day processing period the respiration rate is noted to be in the 10-mg range. This range has been noted in previous studies to be the point where the production of odors subsides substantially. After a 77-day processing period, the compost is noted to be in the 5-mg range, a range where agronomic end use is appropriate with respect to stability.

Final Product Evaluation

Inorganic Analyses

Plant nutrient and metal analyses of both compost products are presented in Table 3. This table represents compost analyses of the final product sampled on day 77.

The plant nutrients analyzed include: nitrogen, phosphorous, potassium, calcium and magnesium. In addition, the pH was also determined. The nutrient content of the compost product was in a range similar to that observed in other MSW compost products (de Haan 1981, Furer and Gupta 1983).

The pH of the RDFU was 8.6. The basic pH of the final compost would benefit the growth of plants in the acidic soils common to the northeast. The use of such a high pH organic amendment in agriculture would reduce liming requirements. In addition, the high pH will limit the mobility and subsequent plant uptake and leaching of heavy metals contained in the compost.

The metal content of a compost product is of significance from an environmental and human health perspective. When metals are present in a high concentration, end usage of the product may result in adverse environmental and human health effects. Consequently, state and federal regulations have been developed which specify the maximum metal concentration and cumulative metal loading rate. The regulations currently in use by most states were developed specifically for sewage sludge but are commonly applied to the potential beneficial reuse of other organic waste materials. The metal levels observed in the pilot study should be compared with the regulatory levels of several northeastern states presented in Table 4.

The metal analyses shown in Table 3 indicate nickel and lead are found at concentrations near or above the regulatory limits of several states. In addition, metal analyses taken throughout the pilot study (unpublished data) indicate the metal concentrations vary considerably and on occasion were found at higher levels than those presented in Table 4. In addition there was no substantial change in the metal concentrations from the initial RDFU. The highest levels of nickel (422 ppm) and lead (2208 ppm) found in the compost are much higher than each state's current regulatory limits. The other metals of concern are found within the regulatory limits.

Several of the samples taken throughout the pilot study were analyzed for TCLP (or leachable) metals. The results of these tests are presented in Table 5. A comparison of the initial RDFU and the composted RDFU (day 77) suggests composting of the RDFU resulted in a substantial reduction of the TCLP metal levels. The reduced metal availability in the composted RDFU is probably a result of the increased humic acid content and cation exchange capacity. During composting, the decomposition of organic matter results in the formation of biologically stable humic and fuluic acid compounds [8]. These compounds have an affinity for cations in solution, a property referred to as cation

TABLE 4 COMPARISON OF SEVERAL STATES SEWAGE SLUDGE BENEFICIAL REUSE REGULATIONS

Pollutant	ME	VT	NH	MA	MA	RI	CT	NY	NY	NY	PA
				Class I	Class II			Class I	Class II	Sludge	Compost I
	PPM										
Cadmium	10	NA	10	2	25	15	25	25	10	25	25
Chromium	1000	NA	1000	1000	1000		1000	1000	1000	1000	1000
Copper	1000	NA	1000	1000	1000	1000	1000	1000	1000	1000	1000
Lead	700	NA	700	300	1000	500	1000	1000	250	1000	1000
Mercury	10	NA	10	10	10	5	10	10	10	10	10
Nickel	200	NA	200	200	200	200	200	200	200	200	200
Zinc	2000	NA	2000	2500	2500	2500	2500	2500	2500	2500	2500

TABLE 5 RESULTS OF THE TCLP ANALYSES (PPM)

Sample	Date	Day	Pb	Cr	Cu	Ni	Zn	Mo	Cd	As	Ag	Ba
			ppm									
ID												
RDFU	1-07	0	<0.3	0.27	1.0	2.3	115.2	<0.05	0.22	<0.50	<0.1	<0.5
RDFU	3-25	77	0.3	0.04	0.7	0.5	8.2	<0.05	0.05	<0.50	<0.1	<0.5

TABLE 6 VOLATILE ORGANIC COMPOUNDS IN COMPOSTED RDFU

Sample	Compounds Detected	Concentration (mg/kg)
Composted RDFU		
Replicate 1	ND[1]	
Replicate 2	Acetone	11.0
	2-Butanone	1.5
Replicate 3	ND	

Notes:

1. ND = No volatile organic compounds detected.

TABLE 7 TOTAL CHROMATOGRAPHICABLE HYDROCARBON CONTENT OF UNCOMPOSTED AND COMPOSTED RDFU

Sample	Concentration (mg/kg)
Uncomposted RDFU	
Replicate 1	10,000
Replicate 2	4,000
Replicate 3	32,000
Average	15,333
Composted RDFU	
Replicate 1	<1.0
Replicate 2	21
Replicate 3	<5.0
Average	7.0

exchange capacity. An increase in this property results in the decreased mobility of positively charged metals [9].

Organic Compounds of Concern

The finished compost product was examined for volatile organic compounds ("VOCs") [EPA Method 8260] and total chromatographable organics ("TCO") [EPA Method 8020]. Results of the VOC analyses are presented in Table 6. Analyses of three replicate RDFU samples indicate no VOCs were detected in two replicates; however, acetone and 2-butanone were detected in one of the replicate samples. There is no published data available presenting VOC analyses of MSW compost. In addition, MSW composting facilities currently operating in the United States have either not performed such analyses or are unwilling to release the test results.

The TCO method provides semiquantitative data on the levels of organic compounds with boiling points between 100°C and 300°C. Compounds detected by this method include: diesel fuel, No. 2 fuel oil, mineral spirits, turpentine, kerosene, gasoline, polycyclic aromatic hydrocarbons and other compounds. The method detects compounds similar to the total petroleum hydrocarbon ("TPH") method; however the TCO method detects a wider range of compounds than the TPH method.

The TCO results are presented in Table 7. In addition to the final product, the RDFU were also analyzed for TCOs at the beginning of pilot study. The results show

TABLE 8 FECAL COLIFORM, FECAL STREPTOCOCCI, AND SALMONELLA CONTENT OF COMPOSTED RDFU

	Replicate 1	Replicate 2	Replicate 3
Fecal coliform[1]	<10	<8.6	9.4
Fecal streptococci[1]	8,100	>6,900	>7,519
Salmonella	ND	ND	ND

Notes:

1. Colony farming units per gram of volatile solids.
2. Not detected.

an initial high concentration of TCOs with a significant reduction during the process. A variety of materials in the RDFU feedstock could be responsible for the high TCO levels observed. These materials include paints, solvents, waste oils and fuels and other types of wastes. Another potential source of TCOs is the aromatic oils from christmas trees. A large quantity of pine needles from christmas trees were observed in the RDFU.

In the composted RDFU, TCOs were detected in one of three replicate samples at a very small concentration. In all likelihood, decomposition and volatilization were both responsible for the observed reduction in TCOs. The decomposition of synthetic organic compounds has been found to be enhanced during composting [10, 11]. Thermophilic temperatures and aeration also enhance the volatilization of synthetic organic compounds.

Salmonella and Fecal Indicator Microorganisms

One of the objectives of the composting process is the maintenance of thermophilic temperatures and the subsequent destruction of human pathogenic bacteria. The final compost product was analyzed for fecal coliform and fecal streptococci bacteria. In addition, the final product was also tested for Salmonella species. The results of these analyses are presented in Table 8. The test results indicate fecal coliform bacteria were found in low populations in the RDFU, while only the fecal streptococci were found in high populations. Salmonella species were not detected in the compost product.

The high fecal indicator populations may be a result of their introduction from a front-end loader used to turn the cure piles and their subsequent regrowth in the cure piles. The front-end loader used in the pilot study was also used in daily landfill operations, and undoubtedly was contaminated with fecal indicator microorganisms associated with MSW. Despite the high fecal indicator populations, Salmonella, a common fecal pathogen, was not detected in the finished compost.

Physical Characteristics

The bulk density and sieve analysis was determined on the final composted RDFU product. The bulk density was 1100 lb/cu yd. The bulk density of the RDFU was noted to decrease from an initial bulk density of approximately 1300 lb/cu yd to 1100 lb/cu yd. A decrease in the bulk density as a result of composting organic wastes is a common observation.

The results of the sieve analysis indicated that approximately 90% of the final product passed a 9.75 mm (3/8 in.) sieve. For most horticultural and agricultural end uses, the final product would not require any screening. However, screening and removal of a substantial portion of the glass fraction would improve the appearance and increase the market value of the final product.

Potential End Use of a Composted RDFU

The following pilot study results indicate a limited potential for utilizing composted RDFU for high value, horticultural end uses.

High Lead Content of Final Product

The lead content of the composted RDFU (which is directly related to the raw RDFU) was high, ranging from approximately 600–2200 ppm. Pending state regulations would in all likelihood limit the utilization of a product with such a high lead concentration.

High Glass and Plastic Content of Final Product

The high glass and plastic concentration decreases the value of the final product. The use of mechanical processes to remove glass and plastic is feasible.

Long Processing Time Required to Produce a Final Product Suitable for Agronomic or Horticultural End Uses

A minimum processing period of 10–12 weeks would be required to produce an end product sufficiently stabilized for high value horticultural end uses. Alternatively, a 5-week processing period is required to produce a suitable landfill cover material.

Due to the above factors, the most appropriate end usage for the RDFU compost is as a daily landfill cover material.

PILOT STUDY CONCLUSIONS

Overall, the results of the pilot study support the use of composting as a technology for utilizing the unders from the production of RDF. Composting proved to be a viable means of transforming the RDFU, in a short period, to a suitable landfill cover material. A higher horticultural end use may not be economically viable, as it would require a long processing period and the removal of glass and plastic. The cost of this additional processing in all likelihood would not be offset by the increased value of the final compost product. In addition, the composted RDFU had a high lead concentration which could severely limit end usage.

CONCEPTUAL DESIGN OF THE COMPOST FACILITY

The results of the pilot study have been used by R. W. Beck to develop a conceptual design and in turn access the economic feasibility of producing landfill cover from the RDFU produced at the Mid-Connecticut Facility. The following summarizes that work.

Design Basis

Based on the Pilot Study, the design basis for a composting Facility to process the RDFU generated at Mid-Connecticut was based on a capacity of receiving 200 ton/day of RDFU for 312 days/year. Although other composting methods would produce an acceptable landfill cover product, we have used an aerated turned windrow process, utilizing a machine to turn the windrow periodically, and 35 days of composting time in order to achieve a stable material suitable for landfill cover. Additional design parameters include: *(a)* aeration flow capacity of 7300 cu ft/min per windrow; *(b)* a building ventilation rate of six air changes per hour; and *(c)* a biofilter with a 15 cu ft/min/sq ft flow rate, with a 3-ft depth used to control odors. All air in the building is to be ventilated through the biofilter in order to control odors produced from the process. In addition, we have allowed for the addition of 5600 gal of water over the course of the 6-week composting period to each windrow to enhance the composting process.

Description of Facility

The conceptual design of the Facility is based on a generic industrial location in the Hartford, Connecticut area in order to conveniently service the Mid-Connecticut project. Figure 3 shows a conceptual site plan of the composting Facility. The complete composting Facility will require approximately a 7-acre site and include security fencing, roads, drainage, the composting building and related outlying structures. The design will have the RDFU arriving at the Facility in the 40-cu yd roll-off containers presently used by CRRA to haul this material to the landfill.

Material Handling

In the building the truck will dump the RDFU on the composting floor at a location near where a new windrow will be constructed. The trucks will subsequently proceed for loading, to that area of the composting building where a composting pile, having completed its 35-day composting cycle, is being reclaimed as landfill cover to be transported to the landfill. During each of the six working days each week, one new windrow will be built and one windrow will be reclaimed for delivery to the landfill.

The main composting building, shown in Fig. 4, is a pre-engineered metal sided structure 250-ft wide by 503-ft long with a nominal height of 20 ft at the eaves and containing space for the installation of 36 windrow piles each 20-ft wide by 107-ft long. Two of the 25-ft wide interior bays will have a height of 32 ft in order to accommodate the tipping of the truck mounted roll offs for unloading of the arriving RDFU. In addition, four 26-ft high motorized overhead doors at each end of the two unloading bays and fourteen 16-ft high motorized overhead doors will facilitate the movement of equipment through the building. Fifteen foot wide equipment lanes will provide access between each group of windrow piles within the building. The arrangement of doors allows trucks and equipment to enter one side of the building and exit the other side, thus minimizing the floor area of the building.

Process Control

The composting process requires a controlled supply of air and the ability to maintain adequate pile moisture. The system for providing aeration air for maintaining aerobic conditions and temperature control of the composting process is comprised of individual air blowers and trenches underneath each windrow to distribute the air. Outside air is drawn though a wall mounted filter, flows to the blower and then is distributed to the corresponding windrow through two 18-in. distribution pipes. These two 18-in. distribution pipes feed the air distribution trenches under each windrow pile (see Fig. 5).

The aeration blower for each windrow will be controlled by the temperature control system, comprised of three temperature sensing probes inserted equally along the length of the pile and monitored via the control system. These probes will be used for control as well as confirming the temperature and residence time required for reduction of pathogens. (The PFRP criteria). The blowers will supply air in response to a temperature signal, with a minimum hourly on-time for maintaining aerobic conditions. Typically the air will be on for 18 min/hr. During the initial pile heat up, a

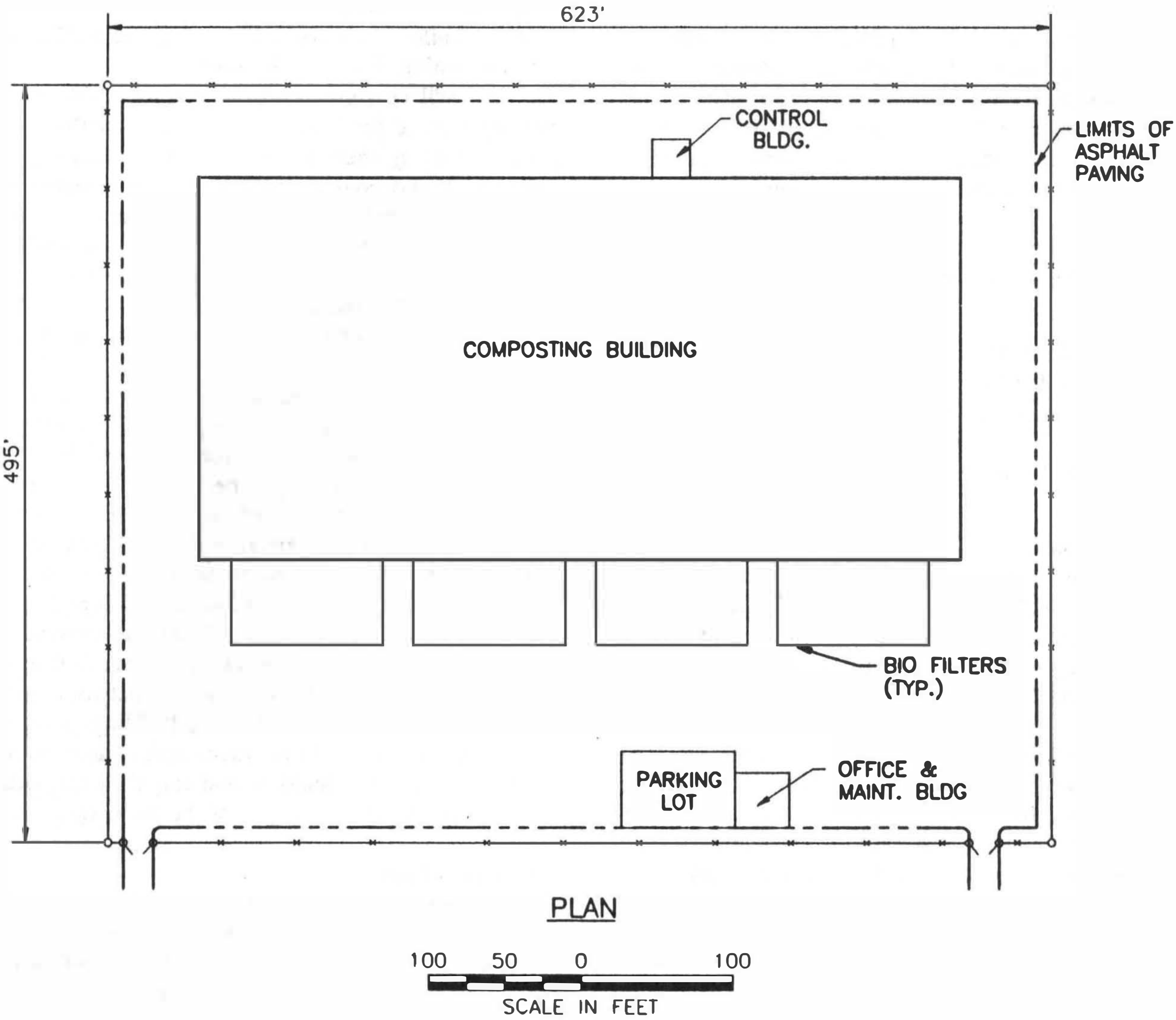

FIG. 3 CONCEPTUAL DESIGN FOR CRRA COMPOSTING FACILITY

minimum amount of air will be used regardless of pile temperature. These temperature probes will be mounted such that they can be moved out of the way for turning of the windrow or for the building or reclaiming of a windrow.

Each windrow will also have a sprinkler system mounted above it which will allow the Facility operators to add water if required, to the windrow during the course of the composting process. Typically, water will be added prior to turning of the windrows in order to allow the water to be well mixed in throughout the pile. The moisture content of the piles is intended to be kept in the range of 30–35% to aid in the composting process. This is less than the typical moisture level of 45–55% due to the high level of inert material in the RDFU.

Odor Control

Odor produced during the compost process is controlled by biofilters consisting of porous media with attached microorganisms that metabolize odorous contaminants from the compost process air stream. The media used for this application will be stabilized compost. Figure 6 shows a schematic arrangement of the biofilter system.

Each of the four biofilter modules are supplied by an air ventilation system ("AVS") which changes the building air up to six times per hour. Two fans in each

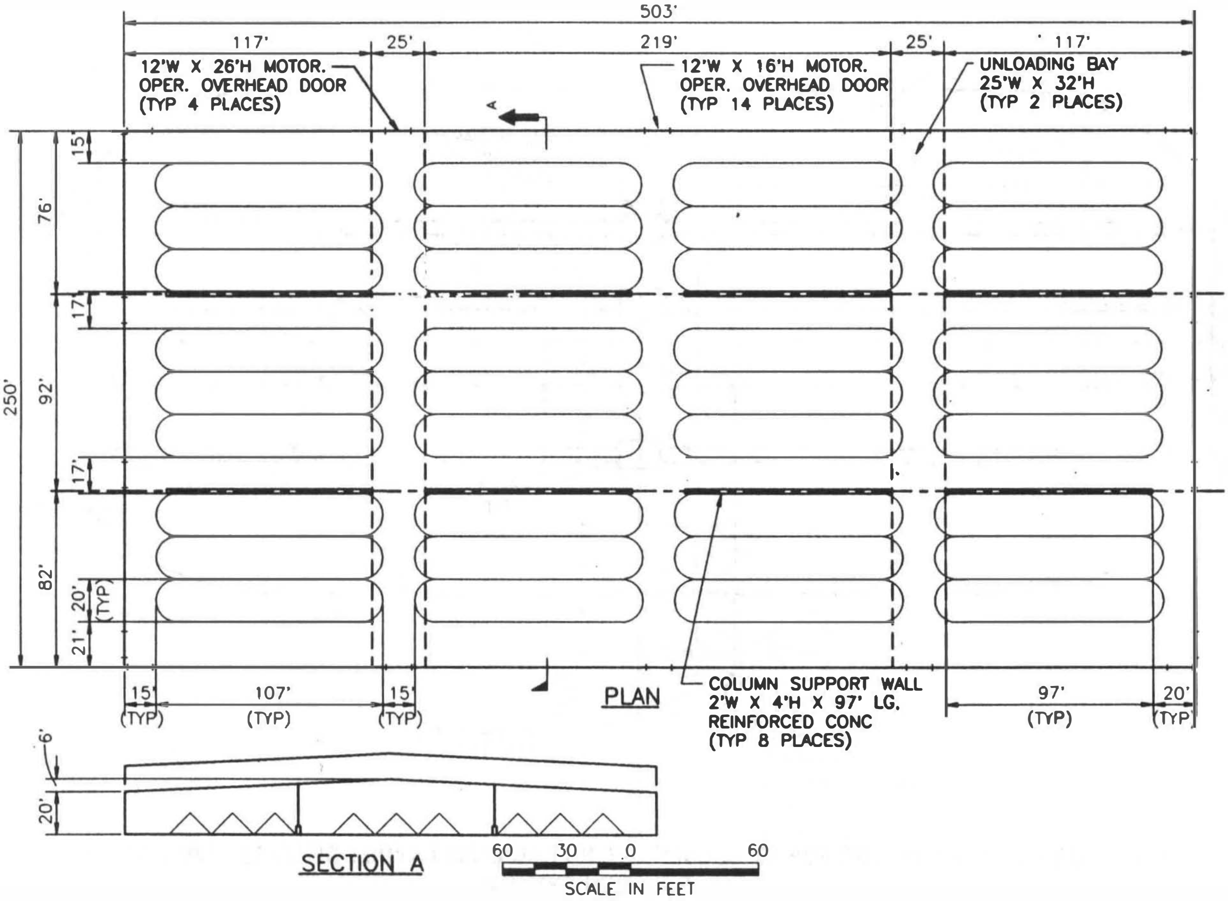

FIG. 4 CONCEPTUAL DESIGN FOR CRRA COMPOSTING BUILDING

biofilter module sends the air to a concrete chamber, equipped with spray nozzles to add moisture to the air stream before it enters the biofilter. This water is added in order to prevent the biofilter media from becoming dry and thus losing effectiveness in controlling the odor. Moistened air leaving the concrete chamber travels through header canals and through interlocking concrete blocks, which diffuse the odor containing air evenly through the filter media.

Mobile Equipment

Material movement will be provided with two Caterpillar Model 966 wheel loaders, equipped with large capacity buckets. Typically, one wheel loader will be used in moving incoming residue into the new pile being built while the second wheel loader will be reclaiming a composted windrow and loading it in the truck mounted roll offs for transfer to the landfill. The other major piece of equipment used at the Facility will be a windrow turner. This conceptual design is based on the use of a SCAT Engineering Model 4833 self propelled windrow turner. This windrow turner is designed to accommodate 20-ft wide piles, 10-ft high and it can turn these piles in two passes.

Balance of Plant

Other systems included in the main composting building are electrical lighting systems, electrical distribution systems for the aeration and biofilter fans, floor and sump drainage systems, two 100 GPM sump pumps, and a public address system. Other site structures include a small control room built onto the side of the main composting building and an office building. The control room will include the data collection, monitoring and control equipment for the temperature monitoring and fan control system. While the separate office building will include a reception area, offices and records retention area and a large shop bay area. The site will also include roads to access all of the doors on the main composting building. A small curing area is included where replacement compost for the biofilter can be cured after its initial 35-day composting process.

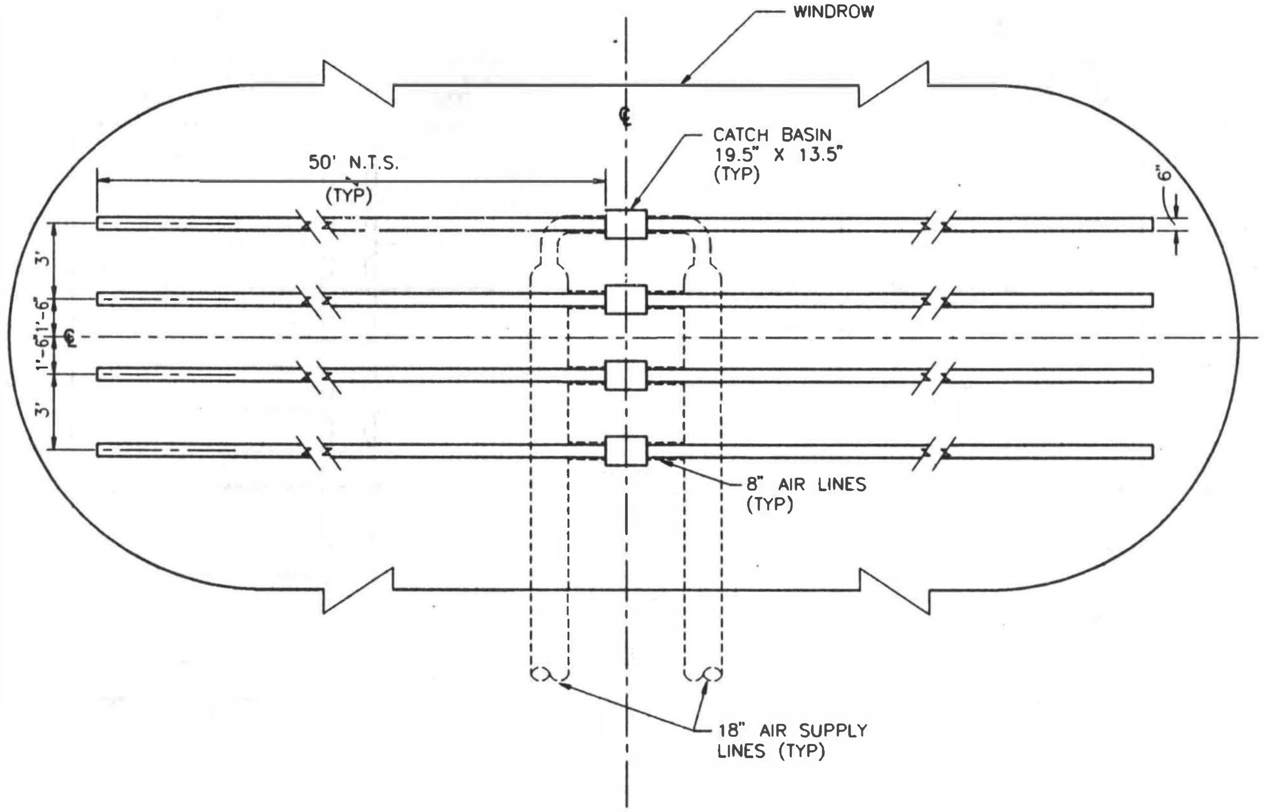

FIG. 5 CONCEPTUAL DESIGN FOR CRRA COMPOSTING FACILITY: LAYOUT OF UNDER WINDROW AIR DISTRIBUTION SYSTEM

There will also be a small weather tower for gathering of meteorological data to support the Facility operations.

FACILITY ECONOMIC PROJECTIONS

The economic projections presented are based on capital and operational cost estimates and the financing assumptions set forth in Table 9.

Conceptual Capital Estimate

Based on the conceptual design and a generic site, the total estimated conceptual capital cost, expressed in 1991 dollars, is $10,295,000. Table 9 summarizes the total construction capital cost for the composting Facility.

This estimate includes a contingency of approximately 6.5% and indirect costs which cover engineering, permitting, construction management and miscellaneous costs.

The capital cost noted above reflects a conceptual design that will produce a landfill cover product while processing the 1200 ton/week of RDFU.

Operation and Maintenance ("O&M") Cost

A projection of the O&M cost estimate is shown in Table 10 based on operating the Facility 6 days/week, 52 weeks/year.

Labor costs are based on a staff of 12 including one project manager, a senior operator, four equipment operators, one clerical and administrative assistant, one mechanic, one assistant mechanic, and three laborers. These basic salary costs have been adjusted by a 35% overhead burden, added to the direct labor costs, to account for vacation, sick leave, overtime, payroll taxes and benefits.

Electricity costs were based on electrical demand and energy usage as projected for the blowers and equipment selected in the conceptual design. This electrical demand and usage were applied to Connecticut Light & Power's Rate Schedule No. 55 to determine the 1991

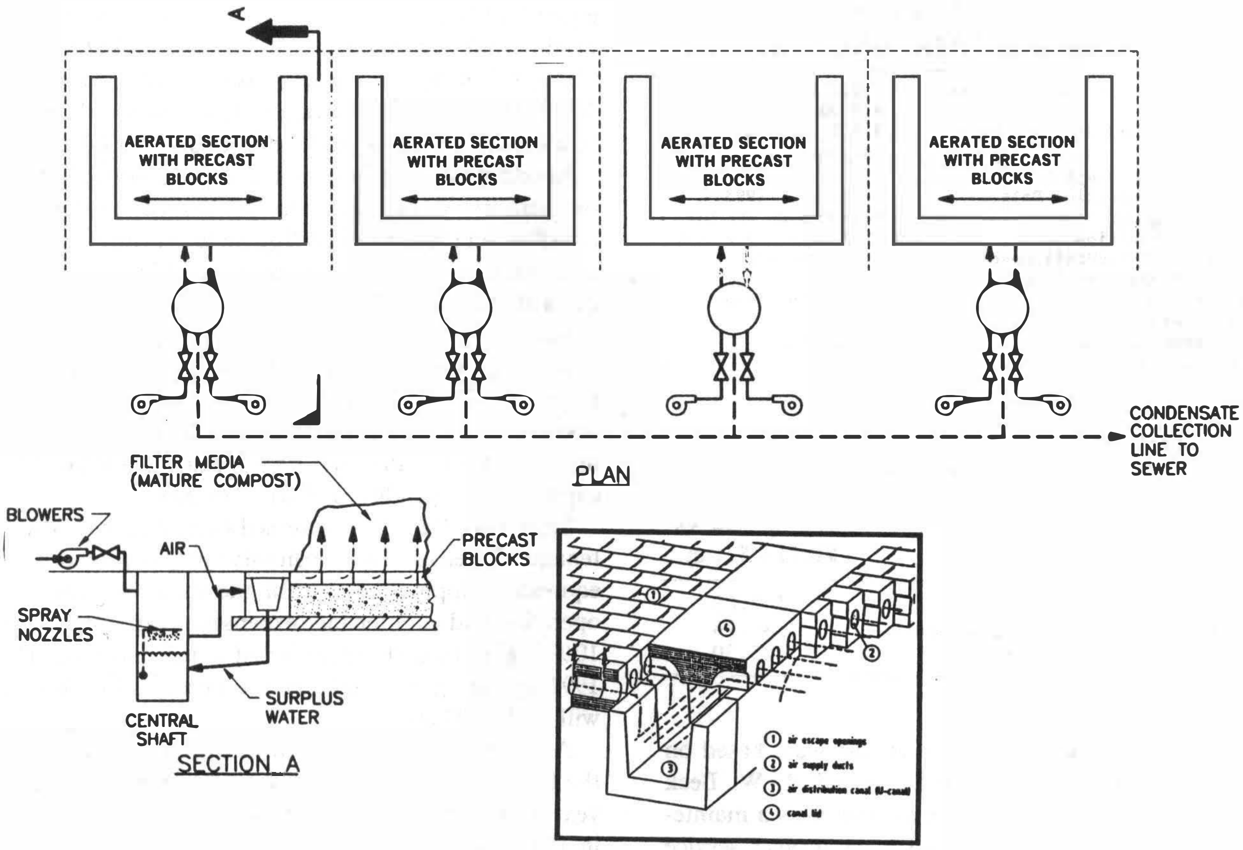

FIG. 6 CONCEPTUAL DESIGN FOR CRRA COMPOSTING FACILITY BIO-FILTER

TABLE 9 PROJECTED CONSTRUCTION CAPITAL COST
(Conceptual CRRA Composting Facility)

	Cost, $1991
Land Acquisition	$ 1,522,000
Site Work and Foundations	2,143,000
Main Compost Building Structure	1,446,000
Compost Building Mechanical	1,624,000
Compost Building Electrical	234,000
Biofilter	1,050,000
Miscellaneous Structures and Work	228,000
Mobile Equipment	685,000
Indirect Costs	800,000
Contingency	563,000
Total Construction Cost	$10,295,000

electrical costs. Water and sewer costs are based on current water and sewer rates in effect at the Mid-Connecticut Project and projected water consumption rates which were based on the design basis study and other water use projections for a facility of this type.

TABLE 10 PROJECTED OPERATING AND MAINTENANCE COSTS
(Conceptual CRRA Composting Facility)

	Cost, $1991
Labor	$ 662,900
O&M Expenses	
Equipment Fuel	37,000
Electricity	296,000
Water and Sewer	44,500
Mobile Equipment Maintenance	30,200
Facility Maintenance	89,400
G&A and Operating Supplies	56,900
Consulting and Lab Costs	40,000
Insurance	82,500
Payment in Lieu of Taxes	63,200
	$ 739,700
Maintenance Reserve	$ 228,000
Total O&M Costs	$1,630,600

TABLE 11 BASE CASE EQUIVALENT TIPPING FEE ANALYSIS PARAMETERS

1991 Construction Capital Cost	$10,295,000
Bond Amount	$13,200,000
Tax Exempt Bond Interest Rate	7.50%
Term of Bond	20 years
Construction Duration	12 months
Commercial Operation Date	January 1, 1993
RDFU Throughput	62,200 tons per year
Compost Production	60,500 tons per year
1991 Cost of Landfill Cover	$2.50 per ton
General Escalation Rate	4.1%
Bond Reserve Fund	10% of Bond Amount
Bond Reserve Fund Income Interest	6.5%
1991 Annual O&M Costs	$1,630,600

TABLE 12 EQUIVALENT TIPPING FEE (Conceptual CRRA Composting Facility)

Scenario	Tipping Fee in $1991, $/Ton
Base Case	$42.89
Increased Capital Requirements	44.74
Increased O&M Expenses	45.30

All operation and maintenance cost were based on recent vendor information and internal R. W. Beck information. In addition to the annual costs a maintenance reserve is included based on a 10-year service life of the Caterpillar Model 966 wheeled loaders, the SCAT Model 4833 windrow turner and a 3-year life on the pick-up truck. Additional funds in the maintenance reserve are budgeted for periodic maintenance of the building grounds.

Consulting expenses and lab testing costs were developed by utilizing an allowance for these expenditures. Payments in lieu of taxes were developed using a rate of $7.90/thousand dollars of evaluation.

Projected Equivalent Tipping Fee Analysis

Based upon the capital cost and operating and maintenance expenses described above, an analysis was developed to determine the equivalent tipping fee for processing of the RDFU in the composting Facility. The financing of the Facility and the resulting annual debt service was based on a twenty year tax exempt bond at 7.5% interest rate. A credit of $2.50, in 1991 terms, was applied to each ton of compost produced in order to reflect the savings to CRRA for the landfill cover it will not have to purchase. The parameters used for the base case analysis are presented below in Table 11.

The projected equivalent tipping fee analysis, based on the above base case parameters, is shown in Table 12. From this analysis it can be seen that the first year equivalent tipping fee based on the incoming tons of residue and expressed in 1991 terms, is $42.89/ton. This fee is substantially less than the avoided cost of $65.00/ton currently viewed by R. W. Beck and CRRA as a conservative cost to landfill this raw RDFU.

In addition to the base case analysis described above two sensitivity cases were also performed to determine the effect on the equivalent tipping fee due to variations and a number of the input parameters. These sensitivity cases shown in Table 12 are described below.

Sensitivity Case A—Increased Capital Requirements: This sensitivity analysis provides the equivalent tipping fee for the scenario where the estimated capital cost of the Facility is 10% higher than that provided in the base case analysis. This would be a total 1991 capital cost expenditure of $11,325,000.

Sensitivity Case B—Increased Operating and Maintenance Expenses: This sensitivity analysis provides the equivalent tipping fee cost for the scenario where the operating and maintenance expenses are approximately 10% higher than those projected in the base case. The 1991 operating and maintenance expenses in this case will be $1,793,800.

A comparison of the equivalent tipping fee costs for the base case and the two sensitivity cases for the first year of operation, 1993, are shown below in Table 12, in 1991 dollars. These values can be compared to the current CRRA approximation of avoided landfill costs of $65/ton.

FEASIBILITY STUDY CONCLUSIONS

The results of the feasibility study in conjunction with the positive results of the Pilot Study show that a composting project to convert RDFU into landfill cover would be economically feasible when compared with the alternative total cost of landfilling this material. The analysis resulted in an equivalent 1991 disposal cost of $42.89/ton of RDFU, which compares favorably with the $65/ton viewed by CRRA as a conservative approximation of the avoided landfill cost to dispose of this RDFU.

The conceptual design which this study is based on is not the only design which we consider feasible. Also we believe that additional engineering can optimize the design and potentially reduce both capital and operating costs.

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