COMPOST FACILITY FEASIBILITY STUDY
RIO RICO LANDFILL
SANTA CRUZ COUNTY, ARIZONA

Prepared For:

SANTA CRUZ COUNTY
Public Works Department
2150 North Congress Drive
Room 119
Nogales, Arizona 85261

Prepared By:

SCS ENGINEERS
2702 North 44th Street
Suite 105B
Phoenix, Arizona 85008

Registered Professional Engineer (Civil)
CERTIFICATE NO.
23413
STEPHEN B.
SMITH
Date Signed 5-15-97
ARIZONA, U.S.A.

May 15, 1997
File No. 10.96035

Environmental Consultants

2702 North 44th Street
Suite 105B
Phoenix, Arizona 85008-1583

602 840-2596
FAX 602 224-0572

SCS ENGINEERS

May 15, 1997
File No. 10.96035

Mr. Ken Zehentner
Public Works Director
Santa Cruz County
Public Works Department
2150 North Congress Drive, Room 119
Nogales, Arizona 85621

Subject: Compost Facility Feasibility Study
Rio Rico Landfill
Santa Cruz County

Dear Ken:

SCS Engineers (SCS) is pleased to submit three (3) copies of the Compost Facility Feasibility Study for Santa Cruz County (Santa Cruz). SCS appreciates the opportunity to assist Santa Cruz with this project. If you have any questions, please call the undersigned at (602) 840-2596.

Sincerely,

Patricia M. Hartshorne, P.G.
Project Geologist

Stephen B. Smith, P.E.
Remediation Services Manager
SCS ENGINEERS

Attachment

PMH/SBS:cfj
F:\DATA\PROJECTS\96035\LTR1.WPD

CONTENTS

CONTENTS - continued

CONTENTS - continued

EXECUTIVE SUMMARY

The Rio Rico Landfill is owned and operated by Santa Cruz County. The landfill currently accepts approximately 7,800 tons per year of produce waste which is received basically separated with minimum contamination. Additionally, within the municipal solid waste (MSW) stream, the landfill receives approximately 5,200 tons per year of yard wastes and 14,000 tons per year of organic waste. The MSW stream is very heterogeneous and the yard waste and organic waste are more difficult to separate.

Santa Cruz County is considering the development of a compost facility to augment its MSW disposal operations and potentially extend the landfill life. The organic material consisting mostly of wood, food waste, yard waste, and other organics would be combined with the produce material and used as a compost feedstock. It was also suggested that the compost feedstock may include sewage sludge from the City of Nogales Wastewater Treatment Facility.

SCS Engineers was retained by Santa Cruz County to perform a feasibility study to identify current composting technologies and usage; identify technologies suitable for use in the County; evaluate recycling activities in conjunction with a composting facility; estimate capital and operation and maintenance costs; and recommend an implementation plan.

The MSW waste stream characteristics were reviewed from previous data and updated. Projected growth patterns from the State Data Center were used to project waste quantities through the year 2030. It was estimated that the current rate of disposal would increase at approximately 2 percent per year.

The current composting technologies are reviewed and summarized in the report. Prioritization of composting alternatives involved evaluating the quantities and technical characteristics of the potential compost feedstock in Santa Cruz County, evaluating performance of the composting system, land use requirements, capital costs, operation and maintenance (O&M) costs, odor constraints, and environmental considerations.

Each of these items are summarized in a tabular format in the report for the composting alternatives of windrow facilities, aerated pile facilities, and in-vessel facilities.

Windrows are the lowest technology option, and are correspondingly the least expensive method of composting. The compost feedstock is laid out in windrows and then turned on a periodic basis until the materials are composted. Depending on exactly which materials make up the compost feedstock, this process can take anywhere between four months and two years. Land use requirements would vary between 8 and 15 acres not including a buffer zone. The capital cost of a facility for Santa Cruz County would range from $180,000 to $380,000. The O&M costs would range from $17 to $21 per ton for a windrow facility that could reasonably control odors and environmental considerations (ranked 3, on a scale of 1 to 5; 1 being best, 5 worst). O&M costs do not include the cost of supplying a bulking agent or a nitrogen source to optimize composting. The capital costs do not include costs for the surrounding buffer area to the compost area required to mitigate odor or aesthetic problems. Only one parcel of property was identified by the County as being available for a potential composting facility during the study. This property is located adjacent to the landfill and a housing development is nearby.

Aerated pile facilities use a higher technology approach, and are therefore more expensive than the lower technology windrow facility. Usually the initial composting is completed in aerated piles, and then the compost is cured in windrows. Many of the constraints identified above for a windrow facility are also applicable to aerated pile facilities. Depending on exactly which materials make up the compost feedstock, this process can take anywhere between 2 months and 1 year. Land use requirements would vary between 6 and 8 acres not including a buffer zone. The capital cost of a facility for Santa Cruz County would range from $400,000 to $700,000. The O&M costs would range from $16 to $24 per ton for a aerated pile facility that could reasonably control odors and environmental considerations (ranked 3, on a scale of 1 to 5; 1 being best, 5 worst). O&M costs do not include the cost of supplying a bulking agent or a nitrogen source to optimize composting. The capital costs do not include costs for the surrounding buffer area to the compost area required to mitigate odor or aesthetic problems.

In-vessel systems use the highest technology approach, and consist of many different types of proprietary systems. The systems utilize forced aeration and frequent turning by rotation or mechanical means within large enclosed chambers. Operations may be computer controlled. Depending on exactly which materials make up the compost feedstock, this process can take anywhere between 3 hours and 4 weeks. Land use requirements would be approximately 2 acres not including a buffer zone. The capital cost of a facility for Santa Cruz County would range from $2,400,000 to $5,000,000. The O&M costs would range from $24 to $40 per ton for an in-vessel facility that could mostly control odors and environmental considerations (ranked 2, on a scale of 1 to 5; 1 being best, 5 worst). O&M costs do not include the cost of supplying a bulking agent or a nitrogen source to optimize composting. The capital costs do not include costs for the surrounding buffer area to the compost area required to mitigate odor or aesthetic problems.

As these composting alternatives were analyzed several fatal flaws were discovered concerning development of a composting facility, regardless of the type of facility. The produce waste has a high moisture content, estimated to be approximately 80 percent with wide variability. The produce waste will require a bulking agent, such as a yard waste or organic waste, to decrease the moisture content to an adequate level to allow the material to compost (less than 60 percent). It is estimated that between 7,800 and 23,400 tons per year of bulking agent would be required. Based on current landfill conditions, it is estimated that about 1,900 tons per year or less than 25 percent of the total needed could be supplied by the landfill operation without providing cost prohibitive recycling operations.

Without an adequate amount of bulking agent, the spoiled produce waste would rapidly create odor problems. One means of potentially trying to control the odor, assuming adequate bulking agent was available, is to optimize the balance of nutrients, specifically the C:N ratio. However, it appears that adequate sources of nitrogen containing materials are also not available. The minimal quantities that are available, such as the sewage sludge from the wastewater treatment plant, are not cost-effective to obtain.

It is recommended that an implementation plan be considered by Santa Cruz County which would determine alternatives other than composting for disposal of the spoiled produce waste. For instance, a common practice in the large agricultural valleys of southern and central California is for these type of wastes to be deposited in a separate agricultural landfill. The materials could also be land applied in agricultural fields and plowed under.

SECTION 1
INTRODUCTION

BACKGROUND

Santa Cruz County is considering the development and utilization of a compost facility to augment its municipal solid waste (MSW) disposal operations. Based on the results of the Material Recovery Facility Feasibility Study previously prepared by SCS (File No. 10.92010, dated October 29, 1992), a significant portion of the MSW stream that is currently delivered to the Rio Rico Landfill was identified as being suitable for composting.

The organic material that is part of the current residential and commercial waste stream includes wood, food waste, yard waste, and other organics. In addition, significant quantities of spoiled produce are currently brought to the landfill during the months of November through May. The spoiled produce material is generally source-separated with minimal contamination and thus could be readily utilized as a compost feedstock.

Removal, processing, and reuse of this organic material from the waste stream prior to disposal could extend the life of the landfill. It was also anticipated that such a composting facility may be able to utilize sewage sludge generated by the City of Nogales Wastewater Treatment Facility.

SCOPE OF WORK

SCS was retained by the County to prepare a feasibility study to address the following issues:

- Identify current composting technologies and usage;
- Identify technologies suitable for application in Santa Cruz County;

- Evaluate development of a compost facility in concert with recycling activities;

- Estimate capital and operation and maintenance costs; and

- Recommend an implementation plan.

These issues are discussed in this report. The second part of the study will involve additional services required for development of the Composting Facility. These additional services would define specific steps necessary for development of the Compost Facility which may include obtaining site and regulatory approvals, identifying and obtaining grants and loan funds, identifying and securing markets for compost material, preparing and reviewing Plans and Specifications, and other services for improvement to the solid waste management program of Santa Cruz County.

SECTION 2
WASTE STREAM CHARACTERISTICS

INTRODUCTION

SCS previously prepared the Materials Recovery Facility Feasibility Study and the Solid Waste Facility Plan for the Rio Rico Landfill. A 2-day physical waste sort was performed on July 29 and 30, 1992 to detail the types and amounts of specific constituents of the waste stream, as discussed in the Materials Recovery Facility Feasibility Study. The waste sort included sorting and weighing 20 representative samples of City of Nogales waste, and a visual characterization of waste was conducted for other self-haul vehicles thought to be mainly residential waste. This is the most up to date information on the composition of the waste disposed at the landfill.

RESULTS OF WASTE SORT

The results of the waste sort conducted in July 1992 at the Rio Rico Landfill are included in the following table:

CONTRIBUTOR	SORTED WASTE (Residential and Commercial)	VISUAL CHARACTERIZATION DATA	TOTAL COMPOSITE	TYPICAL MUNICIPAL SOLID WASTE CHARACTERIZATION[1]
CONSTITUENT	AVERAGE %	AVERAGE %	AVERAGE %	AVERAGE %
PAPER	39.4	8.7	29.2	41.1
PLASTICS	11.6	0.4	7.9	6.5
YARD WASTE	7.5	18.3	11.1	17.9
ORGANIC WASTE	30	29.7	29.8	7.9
GLASS	3.4	0	2.3	8.2
METALS	5.4	9.4	6.7	8.7
INORGANICS	1.3	17.1	6.6	1.6
OTHER WASTE	1.4	16.4	6.4	8.1

1 Decision Makers Guide to Solid Waste Management, United States Environmental Protection Agency, 1989.

The compostable portions of the waste included yard waste (e.g., lawn clippings, prunings, leaves, woody material) and organic waste (e.g., processed wood products, textiles, rubber, leather, food waste, disposable diapers). It should be noted that the impact of waste disposed by the produce industry was not included in the above data collection. This will be discussed below under waste quantity.

WASTE QUANTITIES

Santa Cruz County provided SCS with tonnage amounts for the Rio Rico Landfill for February 1995 through December 1996. Prior to February 1995, waste amounts were visually estimated since there was no weighing scale at the landfill. The tonnage analysis listed the entities bringing waste to the landfill as Nogales charge customers, Santa Cruz County charge customers, the City of Nogales, Avatar, Santa Cruz County, Tubac, Santa Cruz County cash customers, and City cash customers. Waste tonnages for each entity were calculated on a monthly and annual basis, and the percent of the total landfill waste amount was calculated for each entity. Also calculated were the total monthly waste amounts for the landfill. This table is included in Appendix A.

The total monthly waste amount ranged from 2,704.64 to 5,747.59 tons for February through December 1995, and from 2,744.80 to 5,321.01 tons for January through December 1996. The total annual waste amount for the twelve month period from February 1995 through January 1996 was 46,168.75 and for the twelve month period from January 1996 through December 1996 was 46,802.56. In general, waste amounts increased during the months of November through May. This increase is due to the seasonal disposal of produce industry waste by Nogales charge customers.

The total amounts of produce industry waste disposed during 1995 and 1996 were calculated as described below.

- The average base waste amounts for Nogales charge customers in 1995 and 1996 were calculated using the monthly tonnage amounts for June through October (excessively high amounts were not used). The average base waste amount for Nogales charge customers in 1995 was 390 tons/month and in 1996 was 414 tons/month.

- The total annual amount of produce industry waste disposed was calculated by multiplying these average base waste amounts by 12 and subtracting that amount from the respective 12-month totals for Nogales charge customers. The total annual amount of produce industry waste disposed in 1995 was 8,015 tons (17 percent of the total annual waste amount for the landfill) and in 1996 was 7,532 tons (16 percent of the total annual waste amount for the landfill). The average annual percent of produce industry waste is thus calculated as 16.5 percent.

Based on the 1992 waste sort, the 1995 and 1996 tonnage amounts, and the above calculations, the amounts of compostable wastes disposed at the Rio Rico Landfill were calculated for the years 1995 and 1996, as shown in the following table.

TYPES OF COMPOSTABLE WASTE	ESTIMATED PERCENT OF TOTAL ANNUAL WASTE	ANNUAL WASTE TONNAGES	
		1995 (2/95 THROUGH 1/96)	1996 (1/96 THROUGH 12/96)
Yard Waste	11.1	5,125	5,195
Organic Waste	29.8	13,758	13,947
Produce Industry Waste	17 (1995) / 16 (1996)	8,015	7,532
TOTAL ANNUAL COMPOSTABLE WASTE TONNAGES		26,898	26,674

PROJECTED GROWTH

The State Data Center at the Arizona Department of Economic Security provided SCS with current population projections for Santa Cruz County (included in Appendix B). Based on the these population projections, the annual growth rate for the county is 2.3 percent in 1997, gradually decreasing to 1.6 percent in the year 2030, averaging about 2 percent growth per year. Assuming the rate of disposal for yard waste and organic waste at the landfill will increase about 2 percent per year following along with the population increase and that the spoiled produce waste will remain relatively constant, the total annual compostable waste tonnages will increase to approximately 28,350 tons in the year 2000; 32,860 tons in the year 2010; 38,350 tons in the year 2020; and 45,050 tons in the year 2030.

SECTION 3
TRANSPORTATION AND SEPARATION METHODS

INTRODUCTION

Before the waste can be composted, it must be pre-processed, which involves separating the compostable portion of the waste from the non-compostable portion. The way this is accomplished depends on the whether the facility accepts mixed MSW or source-separated compostable waste. The highest rates of composting have generally been accomplished as a result of frequent and convenient collection (e.g., weekly year-round collection), targeting a wide range of organic materials, targeting a high percentage of households and businesses, and offering incentives to encourage composting (including encouragement of backyard composting).

MIXED MUNICIPAL SOLID WASTE

Transportation

The compostable fraction of mixed MSW is transported to the landfill facility mixed with the non- compostable portions of the waste stream. No special transportation needs are required.

Separation

Full-stream processing technologies which accept mixed MSW, as opposed to material recovery facilities that accept source-separated mixed recyclables, have been developed in Europe and the United States. These systems produce a compostable fraction, recovered materials, and residuals.

Compostable materials may be removed before, during, or after composting, or some combination of the three. Separation prior to composting may include diverting loads which contain only yard waste, removing non-compostable wastes by hand or by using screens, magnetic separators, air separators, gravity classification, or other methods of screening. A common method of separating compostable materials from the MSW stream is by a rotating screen called a trommel. Materials may also be removed by hand or mechanical means during the composting process, or after composting has been completed. The amount of sorting required will depend on the waste content of the MSW and the desired use of the final compost.

Advantages and Disadvantages

Advantages to utilizing mixed MSW include:

- Continued use of existing equipment and hauling system;
- No additional public education program is necessary; and
- Generators of waste will not need to increase labor or deal with increased odor or pest problems.

Disadvantages of utilizing mixed MSW include:

- Higher costs for labor and equipment to separate the waste stream;
- Increased difficulty in producing a high quality compost due to higher amounts of undesirable wastes, which may lead to increased contaminant levels (e.g., trace metals);
- Having a large enough preprocessing area to accommodate all the community's waste; and
- The necessity of reloading and hauling non-compostable waste.

SOURCE-SEPARATED COMPOSTABLE WASTES

Transportation

Curbside Pickup--

Curbside pickup of source-separated wastes may include most households and businesses, limited households and businesses, or only seasonal collection (e.g., Christmas trees). Existing public works equipment may be utilized (e.g., front end loaders, refuse packers, dump trucks). Packer trucks are most cost effective since they reduce the unloading frequency. New equipment purchases, such as vacuum leaf loaders or segregated waste haulers, may need to be made. Seasonal increases in the number of temporary workers may also need to be made.

Waste may be placed in plastic bags, paper bags, or directly in trash cans; debagging plastic bags may add problems to waste sorting. If plastic bags are used, they should be transparent to ensure that only compostable waste is included. Studies have indicated that collecting bagged materials requires less time and is more cost effective than using front end loaders to collect unbagged material. Some waste haulers have implemented a dual container pickup system which can load two separate containers at the same time into separate compartments on the truck.

Drop-Off Collection--

Drop-off of compostable wastes can be particularly effective in rural areas and smaller communities, especially where residents already self-haul waste. If only seasonal curbside pickup is utilized, drop-off of wastes may be used in the off-season. Mobile drop-off centers may also be used.

Separation

The waste stream is segregated prior to arriving at the waste facility, and may include yard waste, household food scraps, waste from food processing industries, food service companies, and grocery stores. Some sources of compostable waste are typically segregated as a matter of course, such as the wastes from the produce industry, and may easily be diverted to composting. One method of separation which has been used is division of waste into two components: "wet" (food scraps, yard debris, soiled paper, and disposable diapers) and "dry" (recyclable materials and waste). Although waste is source-separated prior to reaching the facility, some sorting out of non-compostable materials will normally still be necessary.

Legislation may be used to encourage source-separation of compostable wastes. Incentives may include increased MSW tipping fees, using volume-based refuse rates, free or reduced tipping fees for source-separated wastes, banning disposal of yard wastes in landfills, and enforced mandatory participation.

Advantages and Disadvantages

Advantages to utilizing source-separated compostable waste include:

- Lower pre-processing costs since fewer non-compostables will need to be removed from the waste stream;
- A smaller and cheaper waste processing area will be sufficient for pre-processing; and
- Production of higher quality compost due to less contamination, resulting in a more marketable compost.

Disadvantages of utilizing source-separated compostable waste include:

- Having to collect source-separated wastes separately from other MSW, resulting in increased hauling costs and possibly additional equipment;
- More frequent pickups may be needed in warmer weather;

- Special containers may be need to be provided to residents and businesses;
- There may be increased odor problems at the source and at the compost facility; and
- A costly and ongoing public education program will be necessary.

SECTION 4

DESCRIPTIONS OF COMPOSTING REQUIREMENTS AND TECHNOLOGIES

INTRODUCTION

Composting programs can be designed to handle yard wastes (such as leaves and grass clippings) or the compostable portion of the MSW stream (such as food wastes, wood, yard wastes, and other organic materials). Composting programs have also been developed for agricultural wastes, wastewater treatment sludge, or mixtures of all of the above-cited materials.

COMPOSTING REQUIREMENTS

Oxygen

The compost needs to be well aerated, with at least 50 percent free air space. In general, the speed of composting increases with an increase in the oxygen level in the compost. Increased oxygen levels can be achieved by adding bulk to the compost (such as wood chips), and mechanical agitation or turning, which breaks up clumps and mixes the compost. Microorganisms in the compost need at least 5 percent oxygen to survive; if oxygen levels fall below 5 percent, portions of the compost will become anaerobic and produce ammonia odors.

Moisture

To ensure adequate microorganism growth, the moisture content of the compost should fall between 45 to 60 percent, with the desired amount about 50 to 55 percent, and 55 percent as the target amount. If the moisture level is above 60 percent, portions of the compost become saturated and oxygen is displaced, which causes those portions of the compost to become anaerobic. Below about 40 percent moisture, microbial activity slows or stops, and may take days to recover after restoring moisture. Mature compost generally drops to 25 to 27 percent moisture content.

Carbon and Nitrogen Ratio

The ideal ratio of carbon to nitrogen (C:N) in compost is between 25 and 40 to 1, with the optimum at about 30 to 1. Too much carbon (more than 40:1 ratio) in the initial compost will slow the composting process by causing the compost to stay cool. Too much nitrogen (less than 25:1 ratio) in the initial compost mix will allow nitrogen to be lost to the surrounding air, causing ammonia odors. Materials with high wood or paper content have high C:N ratios, and can be added to the compost if the C:N ratio is too low. However, high-carbon materials may resist decomposition. Materials such as urea, animal manure, and sewage sludge have low C:N ratios, and can be added to the compost if the C:N ratio is too high. Since carbon dioxide is released during composting, the C:N ratio will decrease as the compost matures to about 10:1 to 20:1. The C:N ratios for various compostable materials and moisture content is included in the table below.

COMPOSTABLE MATERIAL	C:N RATIO	MOISTURE CONTENT (% wb)	COMPOSTABLE MATERIAL	C:N RATIO	MOISTURE CONTENT (% wb)
Paved Swine Feedlot Manure	3	84	Grass Clippings	19	---
Fresh Poultry Manure	6	75	Mature Sweet Clover	23	---
Fresh Swine Manure	6	90	Legume Grass Hay	25	---
Fresh Cattle Manure	8	86	Potato Tops	25	---
Paved Poultry Feedlot Manure	10	64	Fruit Waste	35	---
Unpaved Cattle Feedlot Manure	10	40	Leaves	40-80	---
Paved Cattle Feedlot Manure	13	77	Peanut Hulls	50	10
Stable Horse Manure	25	50	Cornstalks	60	12
Humus	10	---	Oat Straw	80	10
Alfalfa Hay	12	15	Wheat Straw	130	10
Vegetable Waste - Non-Legume	12	40	Bark	100	---
Yard Waste	14	72	Paper	170	20
Kitchen Waste	15	---	Sawdust	500	25
Green Sweet Clover	16	---	Wood	700	---

Source: North Carolina Cooperative Extension Service, Publication Number EBAE 172-93, electronic revision March 1996 (JWM).

pH

Measuring of the pH level, which indicates acidity or alkalinity, during composting can help indicate the type and intensity of microbial activity and the corrosivity of the compost. A low pH (acidic) indicates that the compost may be anaerobic, which will cause odors. Acidic compost may also dissolve metals in the feedstock or equipment, which may cause contamination of the compost. If the pH of the compost is too high (alkaline), nitrogen is released to the atmosphere, resulting in an ammonia odor. The typical pH of active composting is between 6.0 and 8.0. If the pH of the compost falls below 5.5 or rises above 8.5, microbial activity is significantly reduced.

Temperature

The heat produced during composting is sufficient to maintain proper temperatures for survival of the composting microorganisms. If temperatures are too low or too high, the microorganisms will not survive. Sufficient temperatures are also important for destruction of weed seeds and disease-causing pathogens. Compost temperatures should be taken at different locations and depths, since temperature will vary throughout each pile and will be hottest in the center. Temperature can be controlled by increasing or decreasing the sizes of the piles. Turning the piles can cool the pile by increasing air flow in the pile. The temperature of the compost will cool as the food supply decreases and the pile matures. A table showing critical temperatures for composting is included below.

TEMPERATURE (In Degrees Fahrenheit)	RESULTS
Below 120	Microorganisms will not thrive
120 to 150	Ideal compost temperature range
131 (3 to 15 days)	Temperature needed to ensure destruction of pathogens (see Federal sewage sludge regulations)
149 to 160 (12 hours or more)	Temperature range needed to destroy weed seeds
Above 160	Large slowdown in composting, since microorganisms cannot survive
172	Crash threshold for composting
175	Compost becomes anaerobic

Federal regulations for disposal of sewage sludge specify temperatures and time durations to ensure the destruction of pathogens in the composted sludge (Process to Further Reduce Pathogens [PFRP]). Although compost is not regulated under these requirements unless sewage sludge has been added, a number of states and local governments are using these requirements as suggested safety standards for all compost. The regulations are discussed later in this section. The temperature of the compost materials must reach a minimum of 55 degrees Celsius (131 degrees Fahrenheit) and be maintained for 3 days in an in-vessel or static aerated pile. This temperature must be maintained for a minimum of 15 days in a windrow system, and during this period the windrow must be turned a minimum of five times.

The entire compost pile must reach the target temperature to ensure uniform destruction of the pathogens. This should not be difficult in in-vessel systems, but can be difficult to achieve in piles and windrows. A layer of 6 to 12 inches of finished compost can be placed on the outside of a static pile to ensure that the entire pile reaches the required temperature. The frequent turning of the windrow piles should ensure that the whole pile reaches the target temperature for a minimum acceptable length of time.

The PFRP may be performed early in the composting process when it is easier to maintain the temperatures, but this will also inhibit the decomposition rate. This also increases the risk of regrowth of pathogens later in the process since nutrient sources are still relatively high. An advantage is the reduction of worker exposure to potential pathogens. Performing the PFRP later in the process reduces the inhibition of decomposition and risk of pathogen regrowth; however, it risks running out of nutrient sources before the PFRP is complete.

Cross-contamination should be avoided between compost which has not achieved the optimum temperatures and durations and treated and sterilized compost. This includes the use of clean water for moisturizing and makeup water rather than leachate, the use of clean air rather than air pulled from unfinished materials, no mixing of treated and untreated compost, and the use of different or cleaned equipment for untreated and treated materials.

Time

The time required for producing finished compost can vary by as little as a couple months or more than 4 years, depending on the composition of the waste and the various factors discussed above. Low technology approaches will take longer than high technology processes. Materials which break down slowly during composting include those with high proteins and fats (meats, oils, dairy products) and with high amounts of lignin and cellulose (wood and paper products). These materials could be eliminated from the compost in order to speed processing. Once the compost is mature, the compost should be aged or cured for varying amounts of time, depending on the desired product. In general, the longer the compost is aged, the better the quality of the compost.

FEEDSTOCK PREPARATION

The compost feedstock is prepared for composting by reducing the particle sizes of the organic materials to increase the surface area of the particles. By tumbling or shredding the feedstock particles using a rotating drum, shredder, or hammermill, the particle size can be reduced and made more uniform, which improves aeration and reduces volume. The compost feedstock may then be screened using a drum screen (trommel) in order to size select the material. The composition of the waste is adjusted, if necessary, to establish the desired moisture content and carbon to nitrogen ratio. A bulking agent, such as wood chips, is used to increase air flow through the compost. A starter compost "inoculum" (such as compost already processed at the facility) may be added to increase the speed of biological colonization. The waste is then mixed to homogenize the feedstock, starter compost, and other additives and to distribute the moisture and is then ready for composting.

COMPOSTING TECHNOLOGIES

Yard Waste Composting Programs

Yard waste composting programs have been developed to handle leaves, grass clippings, brush, stumps, and wood. Leaves are the easiest material to compost and are the most common material handled at yard waste facilities. Grass clippings are also compostable, but require more attention because they are higher in nitrogen and moisture than leaves, and thus require more thorough mixing and frequent turning to limit odors. Brush, stumps, and wood are compostable only if they are chipped and take longer to compost; options for these materials include chipping and selling as mulch or as firewood without chipping. Yard waste composting is typically accomplished using windrows or aerated piles, although in-vessel technologies may also be used.

Windrows--

Waste is formed into long piles called windrows. The size of the piles are dependant on the capabilities of the turning equipment, but must be large enough to conserve heat and still allow diffusion of air into the center of the pile. The windrows are aerated periodically by turning, using front end loaders, bulldozers, or other equipment. Special equipment equipped with augers, paddles, or tynes has been developed and is preferable for turning piles, but can be more expensive. The piles should be placed on pavement to allow ease of turning the compost. If the piles are outdoors, leachate may be produced. Temperature control of the compost is more difficult in windrows than in the other types of technologies. Varying levels of technology can be used for managing windrows.

Minimal technology composting involves forming large windrows (generally 12 feet high by 24 feet long) that are turned with a front-end loader only once per year. Because of infrequent turning, decomposition takes longer than in other more advanced approaches, typically requiring one to three years to complete. This process is relatively inexpensive and requires little attention. These facilities generally have a relatively large land requirement. However, the facility will have to be sized even larger to provide a buffer for neighboring residences and businesses, since odors are a problem due to the infrequent turning.

Low technology composting utilizes smaller windrows (generally 6 feet high by 12 to 14 feet long) and more frequent turning (4 times or less per year). Two piles may be combined after approximately one month, and curing piles may be formed after about 10 to 12 months. This approach reduces odor problems, but due to the infrequent turning, odors may still be of concern. Low technology composting is also relatively inexpensive, and the compost is typically produced in about one to two years. A relatively large and secluded site is needed for this technology due to potential odors and large numbers of windrows.

Intermediate technology composting is similar to the low technology approach, but it involves increasing the frequency of turning (preferably using windrow-turning machines) to one to three times every week to 10 days. Turning is usually more frequent during the early stages of composting. Temperature of the piles is monitored daily at different depths. With this approach, the compost product is available after approximately 2 to 8 months, allowing more material to be processed. Capital and operating costs are correspondingly higher due to the increased equipment costs and more frequent operations. Use of windrow-turning machines limits the sizes of the piles, and thus more land may be required due to the larger number of piles. However, odor problems are much less of a concern than the lower technology options, allowing the facility to be located closer to populations.

Aerated Pile--

Aerated piles are a **high technology composting** approach which involves the use of forced aeration and controlling temperatures to optimize composting conditions within the piles. The piles can be approximately 5 to 6 feet high by 10 to 14 feet across, or may be formed into larger windrows. The piles are aerated using lines located in the floor beneath the pile or by plastic tubing within the piles. Aeration may be controlled by a timer or by a temperature feedback system which turns on the blower or suction unit at some pre-determined temperature, cooling the pile and removing water vapor. A layer of finished compost (6 to 12 inches thick) can be placed over the outside of the pile to ensure that the outer areas reach desired temperatures.

The method of aeration may be by blowers or suction, depending on the stage of decomposition. The suction method may be used during the early stages of decomposition so that odors can be controlled by passing the extracted air through an odor control system (e.g., carbon filter, moist peat moss, pine bark chips). Later in the process, the blower method may be used because it requires less power than the suction method. Aeration may be performed for 2 to 10 weeks, after which the blowers are removed and the piles are broken up and turned periodically. Odors are common during turning of the piles.

The advantage of the aeration approach is that the process can be controlled to mitigate odor problems and material can be processed more rapidly. This process requires as little as 6 to 12 weeks to 6 months to produce a compost product. Capital expenses for this method may be less than both windrow and in-vessel technologies, but operating costs will include electricity for the aeration system. Less land is needed for this approach than for windrows.

Municipal Solid Waste Composting Programs

MSW management composting is considered to be a developing waste management technology in the United States. Unlike yard waste composting, a large amount of pre-processing of incoming materials is required prior to composting in order to isolate the compostable portion of the MSW stream, as discussed in the previous section. Technologies for composting of MSW may include windrows or aerated piles, as discussed under yard waste composting programs.

In-Vessel Systems--

In-vessel systems, also called "digesters," use forced aeration and frequent turning by rotation or mechanical means within large enclosed chambers. Most of the in-vessel systems are proprietary. Depending on the system, pre-processing of the compost feedstock may be minimal or extensive. Common in-vessel systems include drums, silos, digester bins, and tunnels, and may be single or multi-compartment units. The vessel itself may rotate, or if stationary, contain a mixing or agitating mechanism to move the waste material. Most of the systems use continuous feed of materials, although some operate using batches.

The main advantage to these systems is the ability to carefully control environmental conditions inside the vessels. Oxygen and moisture levels can be precisely maintained to achieve optimum composting conditions. These operations may be computer controlled for optimum results. Materials may be retained in the vessel for as little as 3 to 4 hours, or for as long as 4 weeks. The in-vessel process may be followed by 3 to 12 weeks of composting in aerated piles or windrows to finish composting the materials. The in-vessel system reportedly provides a more consistent product and fewer odor problems than piles or windrows. In-vessel systems are also more expensive than the lower technology operations due to the increased capital and operational requirements.

POST-PROCESSING OF COMPOST

Following the composting of materials using the various technologies described above, additional processing may be needed to finish the compost to meet market needs. This may include coarse screening the compost to remove larger non-compostable fractions, followed by a fine screening step. Non-compostable materials are returned to the landfill, and larger compostable materials are returned for additional composting. Screening may be done before or after curing of the compost.

In order for the compost to reach a biologically stable condition, the compost is cured in piles. Microbiological activity slows and the temperature cools. The compost must be monitored for moisture, pH, and other environmental requirements just as during composting. The piles may also be force aerated or occasionally turned for passive aeration. Curing may take days to months to complete. Depending on the market for the compost, additional shredding or screening may be performed.

CO-COMPOSTING PROGRAMS

Co-composting is the mixing of two or more types of waste streams. For example, MSW or yard waste may be mixed with sludge or other nitrogen-rich material. The sludge or nitrogen-rich material adds moisture and nutrients to the compost mixture, while yard waste or MSW acts as a bulking agent, adding porosity and absorbing water. Co-composting is an effort to generate a more valuable product and to combine waste operations. Testing of the final product for contaminants is necessary to ensure the quality of the compost; the addition of sludge to a compost mixture is regulated by the Environmental Protection Agency under 40 CFR 503 regulations (discussed below). The quality of the resulting compost and available market will determine the success of the operations.

REGULATIONS

At this time, compost facilities are not specifically regulated under Arizona or Federal regulations. However, facilities which compost sewage sludge are regulated under Federal standards for the use or disposal of sewage sludge (40 CFR Part 503). These regulations are also being used by a number of states and local governments to set suggested safety standards for all compost, even if sewage sludge has not been used. The regulations require that the Process to Further Reduce Pathogens (PFRP) be used to ensure destruction of pathogens in the sewage sludge. In addition, the concentrations of various heavy metals must be below certain concentrations.

According to the Federal regulations, composting PFRP is defined as maintaining the temperature of the compost materials in an in-vessel or static aerated pile at a minimum of 55 degrees Celsius (131 degrees Fahrenheit) and maintaining the temperature for 3 days. Using the windrow method, this temperature must be maintained for a minimum of 15 days; during this period, the windrow must be turned a minimum of five times. The entire compost pile must reach the target temperature to ensure uniform destruction of the pathogens.

SANTA CRUZ COUNTY COMPOSTING TECHNOLOGIES

Land Availability

During the kick-off meeting for this project, the City of Nogales stated that the City did not own much land and that they had no properties available for a compost facility. Santa Cruz County identified one property which may be available, but they did not currently own it. The property is approximately 20 acres in size and located adjacent to the landfill. The property is zoned general rural and the price for the land is approximately $10,000 to $12,000 per acre. Some housing is located approximately 600 feet from this property.

Waste Stream

The largest fraction of the MSW stream in Santa Cruz County which is easily segregated is the produce waste, which makes up approximately 16.5 percent by weight of the total MSW. It is estimated that the annual amount of this waste available for composting is about 7800 tons per year at approximately 80 percent moisture content. It is expected that the relatively high moisture will vary drastically and that the waste will have a relatively high carbon to nitrogen ratio. Based on receipt of this waste between the months of November through May and assuming a five day per week delivery schedule, the average daily tonnage was estimated to be 60 tons. For purposes of this report, the prioritization of composting technologies was performed assuming an average of 7800 tons per year or 60 tons per day of produce waste was available for composting, whichever was applicable to the technology.

Other waste streams which may be separable from the waste received at the landfill include yard wastes and organic wastes, which make up approximately 11 percent and 30 percent by weight of the total MSW, respectively. From experience in other Arizona rural communities, approximately 10 percent of these two waste streams arrive at a landfill in a relatively separated condition with minimal contamination. This is the amount of material that can be separated easily by performing load inspections at the scalehouse and does not require additional integrated solid waste systems, such as source separation or a materials recovery facility (MRF), etc. Making this assumption, there would be approximately 1900 tons per year of this material to use in the composting process. Based on the growth projections for Santa Cruz County, the amount of this material would be about 3700 tons per year in the year 2030. No average daily amount can be estimated based on extreme variability and seasonal fluctuations with this type of waste stream.

It is anticipated that excess moisture in the produce stream may have to be absorbed by using a bulking agent, to obtain moisture contents conducive to composting. The moisture content of the combined material (produce waste and bulking agent) needs to be within a range of 50 to 60 percent by weight to initiate composting. The bulking agents are needed to provide a drier mixture and better aeration. The ratio of bulking agents to compostable materials will vary depending on the type of waste being used, but may be as high as 3:1. Following through with the assumptions for the amount and moisture content of the produce waste, it is estimated that to initiate composting about 7800 to 23,400 tons per year of bulking agents would be required.

The above-mentioned readily separable yard wastes and organic wastes can not provide the bulking agent requirement. Other reliable sources of bulking agents will have to be identified, which may include waste paper, processed wooden pallets, saw dust, wood chips, straw, or other agricultural by-products.

To maintain good composting operations, increased amounts of nitrogen will be needed for biological activity. The above-discussed waste streams and bulking agents have some nitrogen but, in general, do not contain enough to maintain the carbon to nitrogen ratio necessary to optimize the composting process (30:1). Based on the assumption of a bulking ratio of 1:1, the bulking agent has a C:N ratio of 50:1, and that the nitrogen containing material has a C:N ratio of 15:1, approximately 1400 tons per year of nitrogen containing material would be required. Assuming a bulking ratio of 3:1, approximately 3,500 tons per year of nitrogen containing material would be required. For some of the composting technologies discussed later in this report, a supplemental nitrogen source may be required.

Nogales Waste Water Treatment Plant Sludge

If Nogales WWTP sludge is used in the composting process, the sludge will have to be dewatered. The cost for this processing step will probably make the use of the sludge cost prohibitive. There is also some concern that since a portion of the wastewater treated at the plant comes from the Mexican City of Nogales, there may be problems with contaminants, such as heavy metals, due to lesser control on disposal practices.

In addition, if this waste is used in the compost feedstock, it may not be a constant supply since the removal and dewatering of the sludge is periodic rather than continuous. The design of the WWTP made provision for individual sludge lagoons to be cleaned out once every three to six years. The proposed operational scheduling is such that two of the six lagoons would be cleaned out each year.

The total volume of the six active lagoons is approximately 49.2 million gallons, with each lagoon holding approximately 8.2 million gallons. According to information received from the City of Nogales, two lagoons would be dredged to obtain approximately 5 million gallons of sludge at about a 97.5 percent moisture content. This will produce approximately 520 tons of dry sludge solids per year. In conversation with the City of Nogales during the kick-off meeting for this project, it was stated that they were actually cleaning only about one lagoon per year. Therefore, the sludge production would probably range from 200 to 600 tons of dry sludge solids per year. Based on this information, other reliable nitrogen sources will have to be identified, which may include liquid fertilizers, ammonium salts, manures, or other agricultural by-products.

SECTION 5
PRIORITIZATION OF COMPOSTING ALTERNATIVES

INTRODUCTION

SCS has prioritized the composting technologies that are suitable for application in Santa Cruz County. The prioritization has been performed based on a screening of the available composting technologies and composting facilities currently operating in the United States. The screening criteria included system performance, land use requirements, capital costs, operating costs, environmental considerations, and vendor profiles, as discussed below. For purposes of estimating capital costs, it was assumed that the land price was $10,000 per acre and that all required equipment would be purchased and/or installed as a part of the initial capital cost. The land area estimated for each technology does not include buffer area surrounding the compost facility. Operation and Maintenance (O&M) costs are based on projected first year operating expenses and do not include the cost of a bulking agent or a nitrogen source. The prioritization of the technologies follow this discussion.

WINDROW FACILITIES

Windrows are the lowest technology option, and are correspondingly the least expensive method of composting. A table showing a comparison of low technology windrow facilities is included below.

- ***Performance:*** Depending on what materials are composted, the quality of the finished compost may not be as good as in the higher technology approaches. The composting process can be completed in as little as 4 months, or as long as several years, depending on the frequency of turning and the amount of attention to operations. Based on the length of time required for composting with the windrow type of facility, the sizing is based on a 7800 ton per year facility. The waste material (spoiled produce) could come in during the months of November to May, but because of the longer composting times required it would be handled more like it was coming in consistently every day to the facility.

- ***Land use requirements:*** A windrow facility needs to be fairly large to accommodate a large number of long piles. Most importantly, the facility area needs to be large or in a secluded area due to the need for large buffer zones to keep odors from offending nearby residents or businesses. If the facility is located in a secluded area, the potential for future development of the area needs to be considered. Siting of the facility should evaluate such factors as flood plains, steep slopes, soil percolation rates, depth to groundwater, and available water supply.

- ***Capital and operating costs:*** Capital and operating costs are generally low, although with increased turning and the addition of specialized equipment and structures, costs increase accordingly. Initial costs will include land acquisition and land improvements. The minimal equipment needed for a windrow operation is a front end loader used for turning the piles. However, a disadvantage of using a front end loader is the difficulty of properly mixing the piles; thorough mixing is crucial if sewage sludge is to be used in the compost. Special windrow turning equipment is available which speeds up and improves the mixing of the compost. However, because of the operational problems with use of sewage sludge from the City of Nogales in this system, it was not considered viable (periodic availability, inadequate quantity, cost to process into usable form, etc.).

  To improve the final quality of the compost, chippers, shredders, hammermills, and/or tub grinders will be needed to decrease the size of the particles in the compost feedstock, especially if wood or yard trimmings are used as bulk. Screening equipment will be needed as the final step to remove large particles which were not fully composted or inorganics which had not been separated before composting. Mixers may be needed to adequately mix the different types waste included in the feedstock. Monitoring equipment to check temperature, oxygen content, and other parameters will help to decide when piles should be turned or if moisture or other amendments should be added. This is especially important if sewage sludge is added.

Another operating cost that will vary drastically is the cost for the water added to the compost to increase the moisture content, which can be considerable in arid areas. Other potential costs are concrete or asphalt windrow pads, and covered structures or enclosed buildings which may be required due to changes in local or state regulations, in the future. Labor costs increase with the amount of material composted and more frequent turning. Costs will increase if the facility operates below design capacity, there is extensive equipment down time, or if small quantities of materials are separated or shredded at a time

- ***Environmental Considerations:*** Potential environmental concerns with an outdoor windrow operation include the formation of leachate, excessive dust, and storm water runoff. By far the biggest problem is odors, which increase as the frequency of turning decreases. Generally, odors are released when the piles are turned, and will be a problem in the direction the wind is blowing. If the windrow operation is indoors, leachate, dust, and odor problems will be decreased, and an odor control system can be used to filter air venting from the facility. Risks to workers should also be taken into consideration, including pathogens, respiratory aggravation, in addition to normal safety hazards associated with heavy equipment operations.

  If sewage sludge is used in the compost, regulations require that the piles be kept at or above 131 degrees F for at least 15 days, and the piles must be turned at least 5 times during this period to ensure the destruction of pathogens. This increased labor will increase the cost of operation. In addition, sampling of the compost is required to ensure that pathogens and heavy metals are below the required concentrations.

- ***Vendor Profiles:*** See Appendices C and D.

Comparison of Low Technology Windrow Facilities						
Type of Facility	Process Time (Years)	Land Area [1] (Acres)	Capitol Cost ($1,000)	O&M Cost ($/Ton)	Odors	Environmental Considerations
A. Unpaved area, bulking agent, no nitrogen, minimal turning.	2	15	240-300	8-12[2]	15	5
B. Unpaved area, bulking agent, nitrogen, minimal turning	0.75	10	180-260	10-14[3]	4	5
C. Unpaved area, bulking agent, nitrogen, consistent turning	0.4	8	260-340	14-18[3]	3	4
D. Unpaved area, bulking agent, hydrogen, consistent turning, quality compost	0.4	8	300-380	17-21[3]	3	3

[1] Buffer area not included.
[2] Plus cost of bulking agent.
[3] Plus cost of bulking agent and nitrogen source other than sewage sludge.

AERATED PILE FACILITIES

Aerated pile facilities use a high technology composting approach, and are therefore more expensive than the lower technology windrow facility. Usually the initial composting is completed in aerated piles, and then the compost is cured in windrows. Many of the considerations identified above under windrow facilities are also applicable to aerated pile facilities. A table showing a comparison of aerated pile facilities is included below.

- ***System Performance:*** This process requires as little as 2 months up to one year to produce a compost product. Quality will be dependant on pre-processing and post-processing of the feedstock and compost, as discussed for windrows. Aeration of the piles eliminates the need for turning during the initial composting stage, but the final stages of composting involve removing the aeration system and turning the piles until they are cured. Based on the length of time required for composting with the aerated pile type of facility, the sizing is based on a 7800 ton per year facility. The waste material (spoiled produce) could come in during the months of November to May, but because of the longer composting times required, it would be handled more like it was coming in consistently every day to the facility.

- ***Land Use Requirements:*** Aerated piles require less space than the windrows since the odors are not as big of a problem. Facility siting should be evaluated as discussed under windrow facilities.

- ***Capital and Operating Costs:*** Capital and operating cost generally increase for this technology, although less turning is required to complete the composting. In addition to the equipment listed for the windrow operations, piping and blowers are need to force air into and/or out of the piles. In addition, the blowers are ideally controlled by timers or computers which monitor temperature and moisture to determine when the aeration system should be turned on. Odor control systems are used to control odors from the piles. The use of aeration will increase the energy usage at the facility.

- ***Environmental Considerations:*** The aeration process can be controlled to mitigate odor problems. Outdoor facilities may have problems with dust or leachate, as with the windrow facility. If sewage sludge is used in the compost, regulations require that the piles be kept at or above 131 degrees F for at least 3 days to ensure the destruction of pathogens; a layer of finished compost can be placed over the pile to ensure the outer portions of the pile reach the required temperature. In addition, sampling of the compost is required to ensure that pathogens and heavy metals are below the required concentrations. Worker health and safety issues are similar to that of windrow facilities.

- ***Vendor Profiles:*** See Appendices C and D.

Comparison of Aerated Pile Facilities						
Type of Facility	Process Time (Years)	Land Area [(1)] (Acres)	Capitol Cost ($1,000)	O&M Cost ($/Ton)	Odors	Environmental Considerations
A. Unpaved area, bulking agent, no nitrogen	1	8	500-700	16-20[(2)]	3	3
B. Unpaved area, bulking agent, no nitrogen	0.4	6	400-600	16-20[(3)]	2	3
C. Unpaved, bulking agent, nitrogen, quality compost	0.3	6	500-700	19-24[(3)]	2	3

(1) Buffer area not included.
(2) Plus cost of bulking agent.
(3) Plus cost of bulking agent and nitrogen source other than sewage sludge.

IN-VESSEL SYSTEM FACILITIES

In-vessel systems use the highest technology approach, and consist of many different types of proprietary systems. The systems utilize forced aeration and frequent turning by rotation or mechanical means within large enclosed chambers. Operations may be computer controlled. Oxygen and moisture levels are maintained to achieve optimum composting conditions. Materials may be retained in the vessel for as little as 3 to 4 hours, or for as long as 4 weeks. The in-vessel process is followed by 3 to 12 weeks of composting in aerated piles or windrows to finish composting the materials. The in-vessel system reportedly provides a more consistent product and fewer odor problems than piles or windrows. In-vessel systems are also more expensive than the lower technology operations due to the increased capital and operational requirements. A table showing a comparison of in-vessel facilities is included below.

- ***System Performance:*** The in-vessel type systems reportedly provide more consistent products than the other methods. The time the compost is kept in the vessel is as little as several hours and up to 4 weeks, and is followed by 3 to 12 weeks of curing in windrows or aerated piles. Based on the minimal length of time required for composting with the in-vessel type of facility, the sizing is based on a 60 ton per day facility. The waste material (spoiled produce) will come in during the months of November to May, but because of the enclosed systems in the in-vessel systems, it was assumed that all the spoiled produce material would have to be handled daily. This assumption does lead to inefficiencies in use of the in-vessel system, because the system will be dormant for portions of the year.

- ***Land Use Requirements:*** Generally less than for the other technologies.

- ***Capital and Operating Costs:*** Costs for these facilities vary considerably due to the different factors involved and the types of systems, but are generally more expensive than the other technologies, due to increased amounts of equipment and energy demands.

- ***Environmental Considerations:*** Odors may still be of concern; however, the air is filtered and increased monitoring and process control reduce this problem. Dust problems exist for the windrow and pile portion of the process, as discussed earlier. Processing of sewage sludge is as discussed for aerated piles, except that the surface area of the compost is not exposed during the active phase of composting.

- ***Vendor Profiles:*** See Appendices C and D.

Comparison of In-Vessel Technologies

Type of Facility	Process Time (Years)	Land Area [(1)] (Acres)	Capitol Cost ($1,000)	O&M Cost ($/Ton)	Odors	Environmental Considerations
NaturTech Composting Systems	0.14	2	2,400-2,700	30-40	1	2
Bedminster	0.10	2	4,000-5,000	24-32	1	2

MUNICIPAL SOLID WASTE PROGRAMS

Evaluation of Programs

The addition of other portions of the MSW waste stream to a compost program can be beneficial due to the amount of waste which can be diverted from the landfill.

Challenges posed by using MSW include the difficulty and cost of separating compostable organics from non-compostable waste, the potential for contamination of compostable organics which have been separated from mixed MSW (e.g., by heavy metals or pathogens), and the difficulty of removing inorganics which make it into the finished compost. Source-separation of the compostable organics minimizes the above problems, but costs increase due to the specialized collection needed and ongoing public education programs. Several previous studies performed for Santa Cruz County have shown that this is not a cost-effective solution.

Further, a study evaluated the quality of compost produced at eight mixed MSW composting facilities in Minnesota (Johnson, 1994). Parameters of concern were found to exceed the Minnesota Class I compost limits in samples from all but one of the eight facilities; these parameters included cadmium, copper, lead, mercury, nickel, zinc, and PCBs. The sampling results were fairly consistent for each facility throughout the six month sampling period. The larger facilities had consistently higher levels of contaminants, and facilities with better source-separation or recycling programs seemed to have lower levels of contaminants. The study concluded that sampling and monitoring training were needed for facility operators to ensure that consistent and proper methods were used.

BioCycle Survey Results

Types of Technologies Used--

A survey conducted by BioCycle in 1996 regarding MSW composting facilities found a decrease in the number of operating facilities. A total of 41 MSW composting facilities were identified, down from the 1995 number. A total of 15 of the facilities were actually operating, down from 17 in 1995. The operating composting facilities utilized aerated static piles (1), windrows (5), in-vessel (7), aerated windrow (2), enclosed aerated windrow (1), and enclosed windrow (1) technologies; some facilities used more than one method. In addition, facilities in the building, permitting, and planning stages, pilot projects, facilities under consideration, and facilities temporarily closed used in-vessel (18), windrow (6), silo/bay (1), and static pile (2).

Operating Facility Update--

The amount of waste processed at the MSW composting facilities ranged from 3 tons per day to 250 tons per day. Of the 15 operating facilities, nine have been operating for at least five years, and four started operations in 1992. Some facilities have been hurt by the lack of flow control, but others have survived and are back at design capacity levels. The facility at Pinetop-Lakeside, Arizona is one of the few facilities which have been able to make a product that sells consistently. The facility uses a Bedminster system, and obtained the structure and process equipment from previously existing facilities, and therefore for reduced prices.

One of the biggest problems in marketing the compost from the MSW facilities is the difficulty of removing small pieces of glass or plastic from the final compost. This is due to the fact that most of the facilities use mixed MSW, rather than source-separated waste.

SEWAGE SLUDGE PROGRAMS

Evaluation of Programs

The use of sewage sludge in compost is one answer to the large problem of disposal of huge volumes of this waste material, particularly with increasing numbers of restrictions on how and where sludge can be disposed. However, costs of a composting program increase due to the increased amount of sampling and monitoring which are required, and increased attention must be paid to ensure that compost is thoroughly mixed and reaches the required temperatures. Another consideration is that equipment cannot be used on both finished and unfinished compost unless the equipment has been thoroughly cleaned in order to avoid contaminating the finished compost. Additional equipment may be needed to reduce the amount of cleaning necessary. The quality of compost produced from sewage sludge is of primary concern.

BioCycle Survey Results

Types of Technologies Used--

A survey conducted by BioCycle in 1996 regarding the use of sewage sludge (biosolids) in compost showed steady growth in the number of facilities incorporating biosolids as feedstock. A total of 338 projects using biosolids was identified, up from 330 in 1995 (included those not yet opened or temporarily closed). A total of 250 of the facilities were actually operating, up from 228 in 1995. By volume, only a small percentage of biosolids are composted in the United States; land application accounts for a much larger volume. Most of the operating composting facilities utilized aerated static piles (109.5), with lesser amounts using windrows (72.5), in-vessel (52), aerated windrow (8), and static pile (8); fractions indicate facilities which use more than one method. In addition, facilities in the building, permitting, and planning stages, pilot projects, facilities under consideration, and facilities temporarily closed used in-vessel (29.25), windrow (25.25), aerated static pile (24.75), aerated windrow (3.75), and static pile (1).

Compost Quality--

Of 106 operating facilities which completed the survey, 98 stated that the quality of the compost met the 40 CFR Part 503 pollutant limits for "exceptional quality" compost and two did not meet the limits due to accedence of copper or phosphorus limits (six did not answer the question). Two facilities also indicated difficulty meeting the requirements for a "Class A" product due to pathogen levels in the compost. Of the facilities in the development phase, 21 meet the standards and five do not (six did not answer the question).

Operating Costs--

Estimated facility operating costs for composting one dry ton of biosolids were reported by 55 facilities; this is only a general guide since companies base the amounts on different factors. For 29 aerated static pile facilities, estimated costs ranged from $10/dry ton to $531/dry ton; for 13 in-vessel facilities, costs ranged from $8/dry ton to $380/dry ton; for 11 windrow facilities, costs ranged from $6.74/dry ton to $229/dry ton; and for two aerated windrow facilities, costs were $10/dry ton and $425/dry ton.

Bulking Materials Used--

Bulking materials used at aerated static pile facilities consist primarily of wood chips, followed by leaves and grass clippings, with others using recycled compost, manure, paper, coal, wood ash, peanut hulls, and cotton gin and almond residuals. Materials used as bulk at in-vessel facilities consist primarily of sawdust, wood chips, and recycled compost, followed by leaves, grass, manure, septage, wood ash, fish residuals, and rice hulls. Windrow facilities primarily use yard trimmings (including wood chips, grass clippings, leaves, and brush), followed by sawdust, recycled compost, manure, paper, grocery store residuals, and bedding. The aerated windrow facilities reported using wood chips, recycled compost, grass clippings, sawdust, septage, leaves, brush, and beechwood chips from a brewery.

Process Time--

The length of time required to finish composting was reported by the facilities. Static aerated pile facilities reported an average of 31 days of active composting, 33 days of curing, and 40 days of storage. In-vessel facilities reported an average of 23 days of active composting, 26 days of curing, and 59 days of storage. Windrow facilities reported an average of 29 days of active composting, 44 days for curing, and 69 days for storage. Aerated windrow facilities reported an average of 30 days of active composting, 32 days for curing, and 0 to 60 days for storing. Only about half of the facilities reported storing the compost prior to distribution.

Odor Control--

The primary method of odor control reported was biofilters, used by 34 of 43 operating facilities; an additional nine facilities use chemical scrubbers. Ten of 90 facilities reported that their odor control measures were not working effectively; of these 10, five used only process controls, four used a biofilter, and one used process control with bubbling of process water through an aeration tank. The types of odor control measures reported by the different types of facilities were as follows: aerated static pile facilities used process controls (18), biofilters (16), chemical scrubbers (2), ash mixed with biosolids (2), piles covered with wood chip blanket (1), lime stabilization of biosolids prior to composting (1), and none (6); in-vessel facilities used biofilters (14), chemical scrubbers (3), both biofilters and chemical scrubbers (3), process controls (4), and packed tower with water only (1); windrow facilities used process controls (all), and masking agents (1); and the aerated windrow facilities used biofilters. Biofilter media included finished compost, wood chips, mulch, bark compost, or combinations of these materials.

Management Challenges--

From a list of twenty different facility management challenges, the top challenges (in descending order) were reported as weather, compost marketing, odor control, achieving proper moisture content of the initial mix, dust control, equipment breakdown, adequate/consistent solids content of biosolids, and maintaining the desired moisture content during composting. The management challenges reported to be the least problematic were meeting the 40 CFR Part 503 requirements, determining if the end product is stable or mature, operator training, achieving consistent pathogen/vector attraction reduction, and siting/encroaching development on facility borders.

The main challenge reported for aerated static pile was weather, followed by dust control, getting product dry enough to screen, marketing, achieving a uniform mix of feedstocks, and proper pile aeration and adequate air handling systems. For in-vessel facilities, odors were the biggest problem, followed by marketing, weather, maintaining desired moisture content, and accessing the vessels to do temperature monitoring to comply with the Part 503 regulations. For windrow facilities, weather, followed by initial moisture content, equipment breakdown, odors, marketing, feedstock preparation, and finding adequate supplies at reasonable costs were the main challenges.

Equipment breakdowns were identified as a challenge. Aerated static pile facilities reported breakdowns with mixers, grinders, shredders, screens, and conveyors, and difficulty getting parts. In-vessel facilities reported problems with drag chain conveyors, other conveyors, hydraulic systems, wear on moving parts, and blowers. Windrow facilities reported primarily breakdowns with grinders, shredders, mixer, and screening equipment.

SECTION 6
TECHNOLOGY EVALUATION

INTRODUCTION

Based on the requirements and constraints for performing composting in association with the Rio Rico Landfill, evaluations of the suitability of the different types of technologies were performed. However, several key issues have been identified through the course of this project which without resolution make composting non-viable. These are:

1. The spoiled produce waste coming into the landfill is very easy to segregate from all other waste streams. It basically is a source separated waste with minimal contamination. However, the spoiled produce waste has a high moisture content, estimated to be approximately 80 percent with wide variability.

2. The spoiled produce waste will require a bulking agent to decrease the moisture content to an adequate level to allow the material to compost (less than 60 percent). Composting is an aerobic process. It is estimated that between 7800 and 23,400 tons per year of bulking agent would be required.

3. It has been estimated based on current landfill conditions that landfill operations could produce approximately 1900 tons per year of bulking agent. This is less than 25 percent of the amount required. Based on discussions with Santa Cruz County and the City of Nogales, there are no known sources of bulking agents within close proximity of the landfill. Without an adequate amount of bulking agent, the spoiled produce would rapidly turn anaerobic and create odor problems.

4. Several studies performed over the past few years have indicated that efforts to try and increase the amount of bulking agent through a recycling or materials recovery facility are not cost-effective.

5. The land parcel identified for potential use as a compost site is adjacent to the landfill which will optimize transportation costs. However, there is a major housing subdivision to the south of the parcel and development is occurring in the general area which raises the concern level substantially regarding odor control.

6. One means of potentially trying to control the odor, assuming adequate bulking agent was available, is to optimize the balance of nutrients, specifically the C:N ratio. However, it appears that adequate sources of nitrogen containing materials are also not available nor are they cost-effective.

7. All of the above concerns could increase the costs of composting significantly higher than those presented in this study.

WINDROW FACILITY

The least expensive option for a composting facility would be the minimal to low technology windrow system. Equipment needs and operator hours would be relatively low compared to the higher technology options. However, due to the large amount of produce waste that would be used as feedstock and the infrequency of turning, odor is likely to be a problem, and the compost would take a relatively long period of time for completion.

In order to solve the odor problem, windrows would need to be turned frequently and thoroughly, which falls under the category of high technology windrow composting. In addition, the use of sewage waste in the compost would add potential odor problems, and would require frequent monitoring requirements to the turning requirements, also requiring a high technology approach. It is more difficult to adequately process biosolids using a windrow approach.

AERATED PILE FACILITY

These facilities involve frequent monitoring, but no turning during the active phase of composting, followed by formation into windrows during the final phase of the process.

The length of time required for finishing the process is less than for windrows, and the final product is more consistent and less likely to have problems with quality when sewage sludge is used as a feedstock. The amount of land required is generally less than for windrows. The capital costs are somewhat more than for the windrow facilities, but the additional equipment needed is not substantial, consisting primarily of piping and aeration blowers. However, energy costs will be substantially higher due to the use of blowers.

IN-VESSEL FACILITY

Costs for in-vessel facilities are typically much higher than for the other types of facilities due to the larger equipment and operating requirements. However, there is a wide range of technologies and costs, particularly with some types of facilities, such as the modular type units.

SECTION 7
ASSESSMENT OF COMPOST MARKETS

INTRODUCTION

The value of the finished compost will depend on both the measured and perceived quality of the product, the product consistency, and the market demand. Perceived quality factors include the color of the compost, the presence of man-made inerts, and size variations in the particles. Measured quality will include laboratory tests for contaminants (e.g., heavy metals and pathogens), moisture content, pH, soluble salts, seed germination, and nutrients.

The 1996 sewage sludge composting survey conducted by BioCycle reported on the marketing techniques and results of the facilities questioned in the survey. This information is discussed below.

POTENTIAL MARKETS

If marketing the compost is not desired or is not possible, potential uses of the compost by Santa Cruz County and other municipalities within the County include landfill cover, public works projects such as roads and parks, community gardens, and landscaping. Municipalities often provide free compost to residents who are willing to haul the product themselves.

Potential markets which could be pursued include landscapers, nurseries, gardeners, agriculture, golf courses, home gardening, mining re-vegetation projects, topsoil production, bioremediation, landfill cover and closure, greenhouse mixes, and sod and tree farm production. The product could be marketed wholesale or retail, or both. Selling the product, rather than giving away for free, emphasizes the value of the compost to the public. Only two companies reported landfilling compost, due to elevated copper or not meeting the PFRP in windrows.

MARKETING

Most of the facilities in the survey reported that they market their finished compost product. Most of the marketing is performed by the municipalities or public agency instead of being contracted out to a private company. The most effective marketing tools were reported as word of mouth, industry trade shows serving nursery and landscaping companies, and direct sales calls to bulk end users. Other methods included paid advertising, booths at local fairs, mailers, facility tours, free loading with city equipment, contacting companies closing landfills or building golf courses, "on hold" messages on telephone calls, and providing bagged product to potential bulk users. The importance of consistent product quality was noted.

PRICES FOR COMPOST PRODUCTS

Reported prices for the compost ranged from $1/cy for unscreened compost to a high of $45/cy; most prices ranged between $3/cy and $15/cy. Prices are apparently less volatile than for other recyclables.

SECTION 8

CONCLUSIONS AND RECOMMENDATIONS

The conclusions from this study are as follows:

1. The spoiled produce waste coming into the landfill is very easy to segregate from all other waste streams. It basically is a source separated waste with minimal contamination. However, the spoiled produce waste has a high moisture content, estimated to be approximately 80 percent with wide variability.

2. The spoiled produce waste will require a bulking agent, such as yard or organic waste, to decrease the moisture content to an adequate level to allow the material to compost (less than 60 percent). Composting is an aerobic process. It is estimated that between 7,800 and 23,400 tons per year of bulking agent would be required.

3. It has been estimated based on current landfill conditions that landfill operations could produce approximately 1,900 tons per year of bulking agent. This is less than 25 percent of the amount required. Based on discussions with Santa Cruz County and the City of Nogales, there are no known sources of bulking agents within close proximity of the landfill. Without an adequate amount of bulking agent, the spoiled produce would rapidly turn anaerobic and create odor problems.

4. Several studies performed over the past few years have indicated that efforts to try and increase the amount of bulking agent through a recycling or materials recovery facility are not cost-effective.

5. The land parcel identified for potential use as a compost site is adjacent to the landfill, which will optimize transportation costs. However, there is a major housing subdivision to the south of the parcel and development is occurring in the general area, which raises the concern level substantially regarding odor control.

6. One means of potentially trying to control the odor, assuming adequate bulking agent was available, is to optimize the balance of nutrients, specifically the C:N ratio. However, it appears that adequate sources of nitrogen containing materials are also not available. The minimal quantities that are available, such as the sewage sludge from the wastewater treatment plant, are not cost-effective to obtain.

The recommendations from this study are as follows:

1. Alternatives other than composting for disposal of the spoiled produce waste should be investigated by the County. For instance, a common practice in the large agricultural valleys of southern and central California is for these type of wastes to be deposited in a separate agricultural landfill. The materials could also be land applied in agricultural fields and plowed under.

2. A use of easily separable yard waste at the landfill may be for alternative daily cover. The County should investigate the possibility of using this material to conserve landfill space.

APPENDIX A

TONNAGE AMOUNTS FOR RIO RICO LANDFILL

Rio Rico Landfill Tonnage Analysis

1995-96

Entity	Feb.95	Mar.95	Apr-95	May-95	Jun-95	Jul-95	Aug-95	Sep-95	Oct-95	Nov-95	Dec-95	Jan.96	12 Month Total	Percent
Nogales Charge Customers	904.21	1,430.48	1,535.52	1,177.51	685.31	335.74	437.18	432.42	358.11	1,050.28	2,343.40	2,028.58	12,694.70	27%
County Charge Customers	628.35	994.05	858.28	785.00	522.73	604.95	843.98	383.72	472.70	938.05	1,244.04	929.48	8,786.31	19%
City of Nogales	1,424.73	1,840.18	1,528.64	1,741.90	1,658.18	1,618.98	1,706.51	1,610.18	1,481.72	1,455.08	1,887.85	1,525.23	18,854.86	41%
Avatar	13.63	16.63	0.17	7.47	11.92	14.32	18.33	8.80	6.48	10.56	8.04	8.68	121.03	0%
County	28.10	65.07	61.00	23.39	168.89	62.24	104.34	71.45	87.52	55.27	158.93	54.06	920.26	2%
Tubac	27.39	27.39	32.70	-	12.25	-	17.83	-	-	2.72	12.10		132.38	0%
County Cash Customers	281.61	350.38	312.30	362.61	343.61	437.77	414.29	387.81	319.37	325.79	280.78	328.37	4,142.67	9%
City Cash Customers	42.08	17.68	70.71	68.04	54.04	67.65	77.65	20.87	21.74	28.48	12.67	38.81	518.42	1%
Total Tons	3,350.10	4,641.86	4,199.32	4,163.92	3,334.93	3,039.85	3,417.09	2,895.25	2,704.64	3,867.21	5,747.59	4,907.19	48,168.75	1.00

1996

Entity	Jan.96	Feb.96	Mar.96	Apr.96	May-96	Jun-96	Jul-96	Aug.96	Sept.96	Oct.96	Nov.96	Dec.96	12 Month Total	Percent
Nogales Charge Customers	2,028.58	1,887.65	1,515.84	1,611.38	1,152.11	344.82	477.98	1,023.28	372.04	462.15	545.68	1,080.74	12,499.91	27%
County Charge Customers	929.48	1,351.91	1,172.90	1,244.71	1,028.29	498.39	471.27	513.13	597.04	449.17	681.14	868.78	9,704.17	21%
City of Nogales	1,525.23	1,476.66	1,550.85	1,474.80	1,758.82	1,224.25	1,608.82	1,632.56	1,427.45	1,369.78	1,458.42	1,572.44	17,976.08	38%
Avatar	8.68	11.36	7.81	235.51	434.49	190.98	29.19	34.08	38.93	35.53	22.61	34.86	1,084.19	2%
County	54.06	70.98	25.03	58.94	10.68	33.76	43.24	33.42	14.34	154.29	52.77	44.24	593.77	1%
Tubac		16.71	15.43	17.92	3.32	-	27.75	7.53	14.54	13.84	24.54	7.28	148.84	0%
County Cash Customers	328.37	407.40	301.57	364.00	416.81	432.03	488.42	113.19	387.96	355.11	389.73	430.50	4,411.09	9%
City Cash Customers	38.81	98.44	37.88	37.86	17.12	20.57	18.17	18.64	28.27	14.48	41.81	14.40	384.51	1%
Total Tons	4,907.19	5,321.01	4,627.09	5,043.10	4,817.64	2,744.80	3,060.82	3,375.81	2,880.57	2,854.33	3,117.00	4,053.20	46,802.56	1.00

APPENDIX B

ARIZONA DEPARTMENT OF ECONOMIC SECURITY POPULATION PROJECTIONS

ARIZONA COUNTY POPULATION PROJECTIONS
JULY 1, 1997 TO JULY 1, 2050

	1997	1998	1999	2000	2001	2002	2003	2004	2005
Arizona	4,595,375	4,722,075	4,843,025	4,961,950	5,080,800	5,199,150	5,317,475	5,435,675	5,553,825
Apache	65,325	66,200	67,075	67,925	68,800	69,650	70,525	71,375	72,225
Cochise	116,725	118,500	120,175	121,825	123,450	125,025	126,600	128,150	129,675
Coconino	115,925	118,375	120,850	123,325	125,825	128,325	130,775	133,200	135,600
Gila	46,225	47,075	47,900	48,625	49,250	49,850	50,450	51,050	51,650
Graham	32,250	33,275	34,250	35,175	36,025	36,875	37,750	38,575	39,425
Greenlee	8,750	8,825	8,900	8,975	9,050	9,125	9,175	9,225	9,300
La Paz	18,775	19,300	19,825	20,350	20,850	21,325	21,825	22,300	22,800
Maricopa	2,721,750	2,803,325	2,879,500	2,954,150	3,029,150	3,104,075	3,179,150	3,254,375	3,329,550
Mohave	132,650	137,625	142,600	147,525	152,425	157,250	162,025	166,775	171,500
Navajo	85,475	86,625	87,775	88,900	90,025	91,125	92,225	93,300	94,400
Pima	799,375	817,850	836,150	854,325	872,400	890,350	908,225	926,050	943,800
Pinal	148,650	153,075	157,425	161,625	165,750	169,800	173,750	177,625	181,475
Santa Cruz	35,850	36,650	37,450	38,225	39,000	39,775	40,550	41,350	42,150
Yavapai	139,475	143,950	148,425	152,975	157,475	162,000	166,525	171,100	175,700
Yuma	128,175	131,425	134,725	138,025	141,325	144,600	147,925	151,225	154,575

	2010	2015	2020	2025	2030	2035	2040	2045	2050
Arizona	6,145,125	6,744,800	7,363,625	7,993,000	8,621,050	9,242,150	9,863,625	10,499,925	11,170,975
Apache	76,650	81,175	85,775	90,275	94,700	99,125	103,700	108,375	113,225
Cochise	137,025	143,800	150,000	155,425	160,050	163,925	167,400	170,850	174,550
Coconino	147,350	158,750	169,350	179,550	189,875	200,525	211,625	223,275	235,700
Gila	54,600	57,625	60,750	63,750	66,375	68,475	70,175	71,825	73,700
Graham	43,500	47,175	50,675	54,050	57,350	60,525	63,500	66,375	69,250
Greenlee	9,600	9,925	10,275	10,600	10,975	11,325	11,625	11,975	12,325
La Paz	25,100	27,200	29,075	30,650	31,975	33,000	33,900	34,675	35,600
Maricopa	3,709,575	4,101,775	4,516,100	4,948,425	5,390,775	5,839,200	6,296,225	6,768,125	7,264,725
Mohave	194,400	216,000	236,400	254,950	270,775	283,900	295,050	305,650	316,850
Navajo	99,975	105,850	111,850	117,925	123,450	128,775	134,325	140,425	147,275
Pima	1,031,625	1,119,350	1,206,250	1,291,000	1,372,325	1,449,225	1,522,625	1,595,225	1,671,175
Pinal	199,725	216,225	231,225	244,425	255,700	264,975	273,050	280,625	288,525
Santa Cruz	46,250	50,550	55,100	59,800	64,450	69,125	73,900	78,975	84,475
Yavapai	198,050	219,625	240,850	260,775	278,425	293,050	305,675	317,900	331,450
Yuma	171,700	189,775	209,850	231,400	253,850	277,000	300,850	325,650	352,050

Source: Arizona Department of Economic Security, Research Administration, Population Statistics Unit.
Population Projected by State of Arizona Demographic Cohort-Survival Projection Model.

Note: Counties rounded to nearest 25. State total is summation of rounded county totals.

Approved by the Department of Economic Security Director, February 1997

Phone (602) 542-5984
Fax (602) 542-5474

DALIN

APPENDIX C

VENDOR AND EQUIPMENT INFORMATION

VENDOR AND EQUIPMENT INFORMATION

SCS contacted various vendors to get an estimate of the types of equipment available and ranges of costs, as presented below. Prices do not include shipping costs.

FRONT END LOADERS

Valley Equipment Company (leases and sells heavy equipment; prices are for used equipment), Tucson, Arizona (520-888-5587):

Case 621 (2½ yard) 1991: $49,000; 1994: $65,500
Case 821 (3½ yard) 1990: $57,500; 1994: $98,000
Case 921 (5 yard): 1992: $122,000; 1993: $129,900; 1994 (with AC and cab): $142,500

WATER TRUCKS

Valley Equipment Company (leases and sells heavy equipment; prices are for used equipment), Tucson, Arizona (520-888-5587):

Ford F700 (1,800-gallon) 1994: $31,000
Ford F800 (2,000-gallon) 1992: $22,000
International Paystar 5000 (4,000-gallon) 1980 and 1981: $24,500 - $31,000 (new tanks and plumbing in 1990 and 1991)

CHIPPERS

Valley Equipment Company (leases and sells heavy equipment; prices are for used equipment), Tucson, Arizona (520-888-5587): Vermeer 935 (9-inch) 1992: $8,800.

MIXERS

Valley Equipment Company (leases and sells heavy equipment; prices are for used equipment), Tucson, Arizona (520-888-5587): Whitman and Essex mixers (9-yard and 12-yard): $2,600 - $6,000.

SIZE REDUCERS AND GRINDERS

Morbark Sales Corp. (also sell chippers, screens, and conveyors), field representative David Lichlyter, Gilbert, Arizona (517-866-2381):

Tub Grinders - 5 models (#950 up to 1400), ranging from 6-foot diameter to 15-foot diameter tops, hammermill at bottom, knuckleboom loaders on all but the smallest models, portable on 5th wheel, production ranges up to 400 cubic yards per hour for the largest, magnetic separators optional.

Model 1000 (10-foot top) end load, no loader, no long brush, <10-inch stumps: $100,000

Model 1100 (11-foot top) fully equipped, knuckleboom, will handle stumps: $250,000

Milyn, Midland, Texas (800-642-0990): Tub Grinder, need front end loader, 15 tons per hour, 10-foot opening. P10 diesel: $95,000 for smallest, optional magnetic separator: $1500 for smallest.

Rexworks, Milwaukee, Wisconsin (800-292-6294):

Grinders - three models, belt fed, magnetic head and types of belt options, safeguarded so that if metal pieces get in they will drop out the bottom: Biogrind handles yard waste and organics; Maxigrind can process tires; Megagrinder can handle construction debris (anything except metal pieces): $110,000 to $125,000

Buffalo Hammermill, Buffalo, New York (716-855-1202): Hammermill (size reduction machine), use pre-shredder (tub grinder) for larger bulky materials and use hammermill to grind shredded materials with other materials to achieve a uniform particle size; also need conveyor system. Typically used for dry and brittle materials such as wood, but can also handle paper and food waste. Models depend on capacities, types of materials, size of waste, desired size of reduced particles. W-series hammermills used for composting. Price ranges from $5,000 to $65,000.

W-25-H (40 hp, could handle about 100 tons in eight hours): $14,350
W-30-L (being used at a site at 6,000 pounds per hour): $25,000

Banner Welder, Inc., Germantown, Wisconsin (414-253-2900) (have some equipment at Allied Apache Junction facility), load with front end loaders:

Mobile Shredders - uniform sizing, material ejected directly into windrows or use conveyor, Hammer-Knife design, process sludge, food, waste, leaves, grass, bark, wood chips, pallets, packaging, brush, bulky wood waste, fish and poultry waste.

Small (tow behind pickup): $60,000
Mid (need a larger truck to tow): $135,000
Large (40,000-pound): $255,000

Torque Grinder - slow and high speed, up to 15 cubic yards per hour, handles wood waste, construction and demolition material, disaster cleanup, trees, pallets, stumps, furniture, mattresses, and carpet: $300,000

SCREENS

Milyn, Midland, Texas (800-642-0990): Trommel Screen: $65,000 for smallest (easily do more than 20 tons per day)

Banner Welder, Inc., Germantown, Wisconsin (414-253-2900) (have some equipment at Allied Apache Junction facility), load with front end loaders, magnetic heads optional: Trommel Screen - portable, compact size, large perforated screening drum (¼-inch to 3-inch guages, 15-minute changing time, and two hydraulic output conveyors:

Super: $98,000
Max: $135,000

Wildcat Manufacturing, Freeman, South Dakota (800-627-3954), in business 25 years, largest manufacturer (have equipment at Desert Compost in Tucson, Arizona): wide variety, 5 styles: $80,000 to $150,000.

Bulk Handling Systems, Eugene, Oregon (541-485-0999): Build complete turn key system for sorting materials such as MSW or C&D, debris roll with horizontal screen, non-jamming, down to 3/8-inch fines, $1 million system in San Leandro, California (largest yard waste processor); a stand alone screen processing 100 tons per hour $20,000 - $120,000.

Heil Company, Brookfield, Wisconsin (414-789-5533): Usually provide complete systems (shredders, conveyors, screens, separators, controls, walkways, etc.) for MSW facilities and waste energy projects, typical plant size of 200 to 2,000 tons per day. Manufacture trommel screens: entire MSW waste stream goes through screen system, pre-screening and final compost screening; 5-6 feet diameter, 12-feet long and 15-20 feet diameter, 70-feet long: $70,000 to $400,000.

WINDROW TURNERS

Scarab Manufacturing and Leasing, White Deer, Texas (806-883-7621): 6 types, all self propelled; handle windrow sizes from 10-20 feet wide and 5-7 feet high, vary by 2-foot increments; engine configurations Detroit Deisel, Caterpiller, and Cumins; different sized tires and configuration (dual or single on back) or track: $160,000 to $250,000.

Scat Engineering, Delhi, Iowa (800-843-7228), representatives at Bengel Equipment or Tractor (Wayne Fritz or Ken Miles), Phoenix, Arizona (602-256-1422): 3 towed models and 3 self-propelled, elevating face lifts and aerates compost, different size models, 2,000 to 4,000 cubic yards per hour (1,500 to 3,000 tons per hour): $45,000 to $280,000.

Wildcat Manufacturing, Freeman, South Dakota (800-627-3954), in business 25 years, largest manufacturer (have equipment at Desert Compost in Tucson, Arizona): 18 models, three styles (either tractor pulled, mounted on loader, or pulled behind loader). Advantage of using these rather than straddle models (which are much more expensive) is that your vehicle has dual uses rather than just one. Example costing: if you produce 100 tpd, four cycles a season, spend 1-2 hours per day turning, can do 9,000 tons in about 4 hours, minimum 1,500 tons per hour using model LS117A (front of loader style, diesel engine): $70,000.

Pike Agri-Lab Supplies, Strong, Maine (207-684-5131): several models, tractor-driven or self-propelled, rotor action, rotor lengths of 80, 100, and 120-inches, options such as attachment for fleece covering roll, watering system: $13,000 to $30,000.

MONITORING EQUIPMENT

Pike Agri-Lab Supplies, Strong, Maine (207-684-5131): various test kits and compost monitoring equipment, probes, simple to digital, printouts available: for example, simple probes about $75, digital oxygen meter $800, with printer $365; individual test kits (e.g., nitrogen, chroma) $35 - $100, mini lab $780.

Morgan Scientific, Haverhill, Massachusetts (508-521-4440): Compost Monitors - designed for making rapid and repeated measurements at desired depths, data stored for downloading to Windows 95/NT computer. Can be connected to Compost Stability Vessel which maintains a stable temperature and allows measurements of compost stability by respiration.

Plus (temperature and O_2): $1,900
Pro (temperature, O_2, and CO_2): $3,000
Stability Vessel: $1,400

CSC Scientific, Fairfax, Virginia (800-458-2558): Electronic moisture balance, measures moisture loss by loss of weight in about 3 to 12 minutes, rugged, non-technical, accurate, digital readout. Low end cost $3,195.

IN-VESSEL SYSTEMS

Biofermenter/Kelly Green Environmental Service, Exeter, New Hampshire (603-722-6490): Air controlled, European Dutch Tunnel design, essentially a fully enclosed aerated pile. Prototype is a concrete box, 12' x 12', and as long as needed. A box 24-25 feet long will handle about 30 tons per day, and one 30 -32 feet long will handle 40 tons per day. The compost feedstock is thoroughly mixed, then is loaded through the front of the box using a front end loader, filling the box to a height of about 8 feet and the box is sealed. Air is circulated from under the pile; air recirculation is manual or by computer using temperature feedback. Temperatures are measured through ports in the box. Materials remain in the system 2 to 3 weeks, and is considered a stable product. After about one month, the compost is finished. The system does not need to be within a structure. The system reportedly has minimal energy requirements due to the minimal air space, and according to Bob Kelly, takes less than one-third the capital and 20% less operating costs than a Wheelabrator International Process System facility (typically agitated and mixed daily). A new system is being set up in Bermuda.

NaturTech Composting Systems, St. Cloud, Minnesota, (320-253-6255): This in-vessel system consists of retrofitted 40 cubic yard roll-off containers, utilizing conventional parts. Generally the system is set up in increments of 1 to 4 modules connected to a single computer-monitored air system. Air is blown through a manifold into the bottom of the container, through the compost, and pulled off the top. The process controls generally take care of odors, and a biofilter is used as a backup measure. Air flow is monitored using a temperature feedback loop, and Johnson Controls equipment is used. Compost feedstock must be thoroughly mixed prior to composting; heavy duty industrial mixers (e.g., SSI or Harsh International 80 to 100 hp mixers) are suggested for a precision pre-mix. A front end loader is used to load the materials into the containers, and after an approximate 20-day retention time, a roll-off truck is used to dump out the finished compost. The basic system, consisting of uninsulated 4-container system, including biofilter, aeration system, and basic control system is about $180,000. Each container holds 20 tons of material (1,000 lb/cy), and is rated at 1 ton per day; therefore, a basic 4-container system processes 4 tons per day. Currently, a grocery which produces 100 tpd of organic wastes utilizes the system; they have 25 containers and are increasing the number of containers. Another facility processes approximately 20 tpd of biosolids and food waste.

Resource Optimization Technologies, Cornish, New Hampshire (603-542-5291): This company just accepted a job setting up 6 facilities over the next 3 years and is not taking any new work. Their system consists of a 40' x 100' building, 8' high with compost approximately 5-feet high inside. A high speed flail (Scarab or Wildcat type) configured on a crane macerates and turns the compost. Air is sent through a biofilter, and watering systems provide necessary moisture. About 3 weeks of intense composting is followed by moving the compost to the back of the building into static piles. Finished compost is stockpiled in greenhouses since all materials are required to remain on site for 90 days. The entire operation is located on one acre of land, and the optimum volume of materials processed is 20,000 cubic yards per year. One person operates the facility, working about 16 hours per week. MSW, food wastes, biosolids, and books are used as compost feedstock. Some materials are pre-ground, and the final compost is screened. It takes about 3 years to get permitting, etc. before the actual physical construction can begin, which takes about 3 months to complete. A marketing franchise handles sales of their product.

Ag Bag Corporation, Warrenton, Oregon (800-334-7432): All wastes streams present at Rio Rico have been processed using this system. A pilot project was conducted in Scottsdale. The company would not give out pricing or other information over the phone.

Green Mountain Technologies, Whitingham, Vermont (802-368-7291): This system uses modular units called CompTainers, which are essentially roll-off containers. Each container holds about 43 cubic yards, and the system can be adapted to handle 500 pounds to 100 tons per day. The system handles biosolids, food wastes, and the National Park Service is using them for yard wastes. The CompLoader shreds and blends the feedstock prior to loading into the containers via conveyors. The computerized CompTroller aeration system and biofilter collect and treat process air; these can also be installed in a roll-off container to make the entire system transportable. The process can be monitored from an office or by modem. The compost is retained in the containers for 10 to 24 days of active composting, and is then moved by roll-off truck and dumped in the product curing or storage area. One CompTainer is $31,000, with CompTroller and conveyor added the price is $61,700, and with the mixer added the price is $77,200.

STRUCTURES

Structures protect from weather and reduce odor concerns. Corrosion and moisture problems occur in structures, and thus galvanized steel or correctly applied, high quality epoxy finish is needed. May cover only part of the operation, such as mixing or screening areas in wet climates, or the composting area if odor is a problem. Structures cost $10 to $15 per square foot and go up from there. Cheapest are pre-engineered steel frame with wood truss. Above 40' to 50' spans, need pre-engineered steel frame. If there is no ceiling in wood frame, should use pressure treated wood and stainless steel connecting plates. A high quality metal building is $20 to $25 per square foot (totally enclosed, insulated, corrosion resistant). A simple covered roof is about $12 per square foot. (Source: BioCycle, February 1997)

MISCELLANEOUS

Pike Agri-Lab Supplies, Strong, Maine (207-684-5131):

UV stabilized Polypropylene fleece roll coverings for windrows to protect from sun or rain, control dust, 4'x 50'.

Software program to help develop recipes for compost, develop cost estimates, uses Excel for Windows: $250.

APPENDIX D

CASE STUDIES

CASE STUDIES

WINDROWS

The Groundskeeper (Environmental Earthscapes), Desert Compost, Tucson, Arizona: Landscape maintenance contractor in Tucson and other areas. Regional facility in Phoenix, started with 4 tpd of just green waste, currently 85 tpd. Use windrows and reclaimed water for moisture. Loaders turn the piles 4 to 5 times, keep temperatures at 140 to 155 degrees F for 16 weeks, produce 800 cy per month of screened compost. Long term viability questionable due to low cost of landfilling and high cost of composting.

Yuma, Arizona: On-site composting at organic lettuce farm (composting on 20-acre area). Feedstock includes cotton gin waste, steer manure, chicken manure, gypsum, and straw. Layers the materials in 1,100' long windrows, 4' high and 9' wide, approximately 230-250 tons. Use tractor trailer to deliver compost to fields, and tractors and front end loaders to turn compost. Due to the arid climate, needed 24,000 gallons just to prepare the feedstock to the proper moisture content, and then 6,000 gallons per week per line to maintain 55% moisture. In the winter, less than half of this amount of water was needed.

Bee Ridge Landfill, Sarasota County, Florida: In 1991, started with two Morbark tub grinders and two front end loaders; by 1995, added a larger grinder, two more loaders, and a trommel screen. Grind yard trimmings and place in windrows (30' x 12' high) and turn 3 times a month. After 3 months, screen the compost and use for landfill daily cover. Located on 12 acres, used about 216 tons as daily cover in the 1993-94 fiscal year. Grind clean lumber and pallets and gave free to residents and other departments.

Spokane Regional Compost Facility, operated by O. M. Scott and Sons: 43-acre site designed for windrow composting of yard trimmings. Have 500 HP Morbark tub grinder and Recovery Systems Technology Model T-620-S trommel screen (electric motors to reduce noise). Paved receiving area, three windrow areas, maintenance shop, office and visitor center, stormwater retention pond, and noise reduction berm. Active areas of the site are surrounded by a 100-buffer of native vegetation, a cedar fence, and a misting system is used to control off-site odors. Groundwater samples are collected and analyzed quarterly and the finished compost is tested regularly. Yard waste is weighed at the transfer facility and is delivered in transfer trailers; the facility does not have a public drop-off. The bulk of the compost will be marketed and some will be given away.

Cal Waste Recovery Sytems, Lodi, California: Currently process 120 tons per day in windrows piled right next to eachother (no drive space between). Uses about half the space of normal windrows. Process 86 percent yard trimmings, leaves, brush, and garden clippings, and the rest is food process residuals. Remove contamination manually, tub grind with magnetic separator, and place in windrows 8' x 200' long x 160' wide, 60 day retention time. Turn piles using a mechanical agitator which lifts compost onto a conveyor and restacks the pile 15 feet to the left of its original location. Turning is coordinated with temperature monitoring. After active composting, screened out larger materials are returned to the composting process. Compost is cured for 2 to 3 months and is monitored for odor, organic removal, and stable temperature. Marketed to vineyards, agriculture, landscapers, and homeowners after testing.

AERATED STATIC PILE SYSTEMS

Snohomish County, Washington: Large aerated windrow (8' high) on one-half acre concrete pad on farm. Tub grind 20 tons per day of yard trimmings ($8.50 tipping fee) and mix 1:1 with manure. Pile is aerated by a series of 70' long, 4-inch plastic pipes at the bottom of the pile. A 1.5 HP blower connected to two pipes using a T-connection; blower moved from one pair of pipes to next continuously. Screen finished compost with trommel, and market at $10 per cubic yard.

Springfield, Vermont: Town built composting facility to treat sewage sludge when increased development put an end to land application. Treatment costs dramatically dropped with the change from standard dewatering to aerated pile system composting. The process has been able to be flexible in dealing with changes in waste characteristics and the resulting product is marketed.

Longmont, Colorado: Two totally enclosed pre-fab structures, with aerated static piles in the main structure (63,000 sf), and mixing and amendments in the smaller structure (8,250 sf). A smaller heated building has employee facilities. Painted interior with double coat of paint. Buildings cost $1 million. Keeps snow and wind out and odors in.

Cheney, Washington: Aerated static piles in enclosed structure, 32,000 sf pre fab. Process 20 dry tons a month of biosolids with shredded yard trimmings. Haven't needed to use biofilter. Building cost $450,000, not including design; would have made bigger.

Sussex County, New Jersey: Facility originally outdoors, but materials got wet and there were bad odor problems. Now have 4 buildings (2,400 sf each) for aerated static pile composting and one for curing. Process 4 dry tons per day of biosolids in piles, which are aerated using a computerized temperature control system. Buildings are prefabricated steel structure with aluminum walls. A sixth building has an open end and is used for wood chip storage. Each main building (structure only) cost $50,000. Still get odor complaints, but they are few and far between. Every 5 years they need to sandblast the interior steel supports.

Davenport, Iowa: Built $1.1 million, 122,000 square foot, steel frame building, steel supports covered with 2 coats of high performance epoxy-based paint. The building is rectangular and is divided into sections. There is an enclosed main aerated static pile composting room (66,000 sf), a compost process and biofilter area (4,500 sf), and bulk agent storage, curing, and screening area (56,000 sf). Would increase the interior lighting if they did it again.

IN-VESSEL SYSTEMS

Ag Bag, Scottsdale and Tempe, Arizona Demonstration Project: Planned joint pilot project using in-vessel technology. The pilot consisted of curbside collection of green waste, chipping and grinding the waste, and blowing into two large plastic bags (Ag Bag technology). Once filled, the bags are sealed for 2 to 3 months. The bags are equipped with monitoring guages. The final compost will be tested for suitability as a soil amendment. Total cost for the demonstration project is $9867.50 plus $3500 for testing.

Ag Bag, Edwards Air Force Base, California: Process 150 tons of yard trimmings per month and wood residues and horse manure. Chose system to reduce dust, debris, odors, and leachate in high wind and low moisture in area. Takes 4 to 6 people 1 to 2 days to grind, transport to bag, and fill bag. Grind material in Maxigrind 460G grinder, mix with water, and transport by dump trucks to motorized bag filler, which fills 3 to 5 tons per minute and moves to next bag when filled. Each bag is about 10' x 200', and holds 200 tons (500 cubic yards). Includes two aeration tubes and a blower unit (can hook to 3 bags at one time). Temperature is monitored through portholes. Composting takes 2 to 6 months, then stored in 30' long concrete block bins prior to screening using a trommel with 0.5-inch mesh. The bags can only be used once. Cost about $14.50/ton for Ag Bag.

Spectraserve Compost System, Whiteman Air Force Base, Missouri: Similar to concrete mixer; chose because of space constraints (located in 1,200 square foot area), labor savings, fewer equipment requirements, and controlling odors and vectors. Air Force tested and began using. Feedstock includes yard waste and wood pallets and crates; food residuals, cardboard, and biosolids were also tested, but would need to buy another system before adding these to the waste stream. Materials are collected curbside or dropped off at 24-hour area at facility. Feedstock is ground in tub grinder and loaded into system using a conveyor about 7 times a month; manpower to load, unload, and monitor is about 10 hours a week. Process controller monitors temperature, oxygen, and moisture. Multiple units can be linked to a single computer, rotated as needed for 72 hours; capacity to process 10 tons in 72 hours. Screen finished compost with a portable Satellite Screen. Cost of $20 to $25 per ton. Only problems have been with the computer, but they were able to be fixed via the modem in the computer.

NatureTech, Saint Louis Produce Terminal, Saint Louis, Missouri: Currently permitting a facility to handle 13,000 tons of produce, cardboard, and pallets annually. Will be capable of handling 16,000 tons per year using 12 units (40 cy each). Facility will cost about $175,000. Product will be marketed at groceries and nurseries.

Resource Optimization Technologies (ROT), Hanover, New Hampshire: Will build facility at old landfill, will use high speed flail agitator to turn feedstock inside enclosed building, biofilter used for emissions. Will process 16,000 cubic yards per year, capital costs about $400,000. One quarter food residuals from Dartmouth College, yard trimmings, and paper, and Hanover will supply biosolids, yard trimmings and organic feedstock from commercial and institutional facilities.

Celto Canadian Bio-Reactor, Berkeley, California Transfer Station: Demonstration pilot project. Will take food residuals from produce markets, restaurants, etc. Feedstock put in reactor from top, and inflatable rubber bladders move the materials down through the reactor and provide aeration. Follows a 12-day cycle, 3 tons per cycle. Horizontal auger system moves contents out of bottom and then compost is cured.

Bedminster, Marietta, Cobb County, Georgia: Bedminster and Cobb County Co-composting facility (1996), $23 million facility built to handle 300 tpd sewage waste biosolids and 160 tpd MSW biosolids. Fully enclosed, 250,000 square foot facility using 5 rotating Eweson digesters (16' diameter and 200' long); compartmentalized rotary vessels which serve as bio-mechanical preprocessing and composting devices. Mechanical separation of metals and air treatment system, does not shred or grind waste. Unsegregated residential, commercial, and institutional garbage bags are loaded into digester and are broken open inside. Microbes in digester biodegrade the biodegradable portions of the garbage and sludge. Non biodegradable portions are screened off and landfilled. After 3 days, material is rough screened, transferred to aerated static piles for secondary composting and curing. Compost from static piles is fine-screened, and is then ready for storage and market. Facility shut down in August 1996 due to odor problems, and 2 weeks later there was a fire in the composting hall. Another fire occurred on the tipping floor (no MSW was there) in December 1996. The reopening date was thus delayed.

Other Bedminster facilities are located at Pinetop, Arizona (1991), Big Sandy, Texas (1972), and Sevier County, Tennessee (1992). Waste handling at these facilities ranges from 12 tpd MSW and 6 tpd sewage sludge at the Pinetop facility, to 150 tpd MSW and 75 tpg sewage sludge. A number of other facilities are planned, in the permit stage, or have a pilot running.

<u>Consolidated Envirowaste Industries</u> (CEI), Abbotsford, British Columbia, Canada (800-667-1942): Company selected to design, build, finance, and operate an organic waste composting facility for Capital Regional District (Canada) for $4.5 million. The facility will take in approximately 20,000 metric tons/year of materials. Will use in-vessel and outdoor composting; the plant will receive tipping fees and sell the compost.

Owns and operates an $8 million composting facility on 30 acres in Abbotsford, B.C. Processes variety of source-separated organics, can operate at 90,000 metric tons per year (operating at half capacity). The tip fees are $40 to more than $70/ton (landfill tip fees are about $70/ton around Vancouver). Dry materials are processed on a 5-acre composting pad in windrows for 3 to 9 months, turned periodically with front end loaders. Stormwater is collected in lined ditches and stored in an aerated lagoon system; water can be used to add moisture to compost via an underground piping system. Any unused leachate is directed to engineered pond and marsh for treatment prior to discharge. Wet materials are composted in an automated agitated bay/channel system in a 15,000 square foot building (agitators and controls from International Process Systems) which walks the material through system, eventually to a roofed area where it is periodically turned with front end loaders. Exhaust is sent through biofilter. Finished product is screened, stored or pelletized and bagged-sell bulk and bagged product.

<u>Professional Systems Associates, Inc.</u> (302-999-1665) (internet advertisement): Solid Waste Processing Module - complete processing, recycling and resource recovery facility with composting equipment; designed to process up to 1,000 tons per day municipal, commercial, and light industrial solid waste and up to 350 tons per day of dewatered sewage sludge; Sewage Sludge Composting Module - in-vessel co-composting of sewage sludge and solid waste fraction. Available for dismantlement and relocation.

<u>Wright County, Minnesota</u>: $14 million, 5-year-old MSW composting facility closed, unable to compete with landfill fees. Was one of only 15 MSW composting facilities nationwide (and among the largest). Peak was 230 tpd, dropped to 85 tpd; dropped tipping fees, but still couldn't compete with landfill fees of $36 to $43 per ton. Had depended on flow control, but the regulations were found to be unconstitutional. Used Buhler technology.

OTHER

San Diego Naval Station, Navy's largest composting facility. Due to space limitations, use bin wall system instead of windrows; 100' x 500' composting pad, five bins (20' x 26' x 10'). Began operations in July 1996, capacity to process 900 tons of yard trimmings and 740 tons of cardboard and paper annually. Feedstock materials are screened, and yard waste and wood are ground in Rexworks Maxigrind 460G with high-power magnetic attachment on output conveyor. Extended radial stacking conveyor loads mulch and other products into roll-offs.

APPENDIX E

REFERENCES

REFERENCES

BioCycle. Volume 36, Number 1 (January 1995); Volume 37, Number 11 (November 1996); Volume 37, Number 12 (December 1996); Volume 38, Number 1 (January 1997); Volume 38, Number 2 (February 1997).

The Composting Council. *Compost Facility Operating Guide: A Reference Guide for Composting Facility and Process Management.* 1994.

Environmental Protection Agency. *Waste Prevention, Recycling, and Composting Options: Lessons From 30 Communities*. February 1994.

Epstein, Eliot and Engel, Peter. Solid Waste Composting Public Health Aspects: Odors and Bioaerosols. In: Solid Waste Association of North America, *32nd Annual International Solid Waste Exposition Proceedings*, August 1-4, 1994.

Goldstein, Nora and Steuteville, Robert. Steady Climb for Biosolids Composting. Biocycle, Volume 37, Number 12. December 1996.

Goldstein, Nora, Steuteville, Robert, and Farrell, Molly. MSW Composting in the United States. Biocycle, Volume 37, Number 11. November 1996.

Hoyle, Paul T. The Natural Solution to Waste Disposal: Successful Bedminster Experience. In: Solid Waste Association of North America, *32nd Annual International Solid Waste Exposition Proceedings*, August 1-4, 1994.

Johnson, George E. Compost Product Quality: A Case Study of Eight Facilities. In: Solid Waste Association of North America, *32nd Annual International Solid Waste Exposition Proceedings*, August 1-4, 1994.

Razvi, Aga S., O'Leary, Philip R., and Walsh, Patrick. Solid Waste Composting: Lesson 2 -- Composting Municipal Solid Wastes. In Lesson 2 of 8, C240 A184b Solid Waste Composting correspondence course (University of Wisconsin), originally printed in Waste Age Magazine from July 1989 through March 1990, updated May 1995.

Shortridge, Julie. Municipal Solid Waste Composting: Is It Right for Your Community? Minnesota Extension Service, University of Minnesota. 1993.

Solid Waste Report. Local Composting Plant Allows Towns in Vermont to Market Recycled Sludge. Solid Waste Report. September 19, 1996.