NEW JERSEY DEPARTMENT OF ENVIRONMENTAL PROTECTION

SCIENCE ADVISORY BOARD

FINAL REPORT

OUTDOOR FOOD WASTE COMPOSTING

Prepared for:

Commissioner Catherine R. McCabe

Prepared by:

Ad Hoc Work Group

Approved by:

NJDEP SCIENCE ADVISORY BOARD

Judith Weis, Ph.D. (Chairperson)
Clinton J. Andrews, Ph.D., P.E.
Lisa Axe, Ph.D.
Michel Boufadel, Ph.D., P.E.
Anthony Broccoli, Ph.D.
Tinchu Chu, Ph.D.
John E. Dyksen, M.S., P.E.
John T. Gannon, Ph.D.
Michael Gochfeld, M.D., Ph.D.
Charles R. Harman, M.A.
Richard H. Kropp, M.S., P.E.
Robert J. Laumbach, M.D., MPH
Peter Lederman, Ph.D., P.E.
Robert J. Lippencott, Ph.D.
Tavit O. Najarian, Sc.D.
Nancy C. Rothman, Ph.D.

April 22, 2020

Members of the Ad Hoc Work Group and their Standing Committee affiliations:

Peter Strom, Ph.D., Chairperson (Water Quality and Quantity)
Joann Held, M.S. (Climate and Atmospheric Sciences)
Howard Kipen, M.D., M.P.H. (Public Health)
Uta Krogmann, Ph.D.[1]

[1] Dr. Krogmann, a non-SAB member, is a Professor and Solid Waste Extension Specialist at the School of Biological and Environmental Sciences and the NJ Agricultural Experiment Station, at Rutgers University.

Table of Contents

Preface

The New Jersey Department of Environmental Protection Agency's (NJDEP) Site Remediation and Waste Management Program (SRWMP) has asked the Science Advisory Board (SAB) to provide scientifically based information that could be used to inform the implementation of regulatory changes needed to facilitate outdoor food waste composting in New Jersey. In doing so, the SRWMP posed to the SAB a series of charge questions (see Section 1) and information needs (Appendix 1). In response, the SAB formed a Work Group to deliberate on this request. This report addresses the charge questions and needs by providing relevant background as well as more detailed scientific information.

1. Background

Based on 2017 data (USEPA, 2019b), food waste is the second largest component (15.2%), after paper, of municipal solid waste (MSW) in the USA (Table 1-1). Unlike with paper, which is 65.9% recycled, only limited recycling of food waste has been achieved (6.3% composted). In contrast, 69.4% of yard trimmings is composted.

Table 1-1. Municipal solid waste (MSW) generation and management in the USA, 2017. (Based on USEPA, 2019b.)

Material	Generated		% of generation managed by:			
	millions of tons	%	Recycling	Composting	Combustion	Landfilling
Paper	67.0	25.0	65.9	-	6.7	27.4
Glass	11.4	4.2	26.6	-	13.0	60.4
Metals	25.1	9.4	33.3	-	11.7	55.1
Plastics	35.4	13.2	8.4	-	15.8	75.8
Rubber and leather	9.1	3.4	18.3	-	27.3	54.3
Textiles	16.9	6.3	15.2	-	18.8	66.0
Wood	18.0	6.7	16.7	-	15.8	67.5
Other materials	5.1	1.9	28.4	-	13.1	58.4
Food, other*	40.7	15.2	-	6.3	18.4	75.3
Yard trimmings	35.2	13.1	-	69.4	6.0	24.6
Misc. inorganic wastes	4.0	1.5	-	-	19.6	80.5
Total MSW	**267.8**	100	**25.1**	**10.1**	**12.7**	**52.1**

* Includes collection of other MSW organics for composting.

The State of New Jersey has expressed interest in reduction and improved management of food waste. For example, P.L.2017, Chapter 136, approved July 21, 2017 (NJ Senate Bill 3027) "Establishes [a] State food waste reduction goal of 50 percent by 2030." NJ Assembly Bill 2371, which requires large food waste generators to separate and recycle food waste, has just become law in April 2020.

While there is a desire to encourage food waste composting as an environmentally beneficial, sustainable waste management/recycling process, there is a need to prevent environmental problems from arising. A set of regulatory requirements is needed to guide composting activities; these should be based on the best available scientific research. This would encourage composting by implementing the least restrictive regulatory requirements possible while still protecting public health and the environment.

Currently, source separated food waste is a Class C recyclable material in New Jersey, and thus composting of food waste requires a Class C recycling general approval. In the past, there have been a handful of food waste composting facilities in the state, but they have closed due to operational problems such as odor nuisances and leachate issues. As of January 2020, there are no operating Class C food waste composting facilities in the state. However, there is one Research, Development, and Demonstration (RD&D) facility in operation; a second has been permitted by the Division of Solid and Hazardous Waste (DSHW) but is awaiting permits from other Programs in NJDEP. Because of past environmental issues, such facilities have had difficulties in complying with environmental rules for air (odor) and water (surface/groundwater).

This report considers outdoor composting, which might be the least expensive (and therefore most economically viable) approach. While not considered here, the potential roles of enclosed composting and the use of food waste as animal feed, in producing renewable energy (e.g., anaerobic digestion at water pollution control plants or in stand-alone facilities) and other forms of recycling and reuse should not be ignored.

2. New Jersey Current Regulatory Framework

All regulated recycling activities in NJ are governed by the New Jersey Administrative Code, Title 7, Chapter 26A. These regulations were promulgated pursuant to the Solid Waste Management Act, N.J.S.A. 13:1E-1 et seq., particularly the New Jersey Statewide Mandatory Source Separation and Recycling Act, N.J.S.A. 13:1E-99.11.

As provided at N.J.A.C. 7:26A-1 et seq., source separated food waste is considered a "Class C recyclable material." The current regulations only allow food waste composting operations to be conducted in fully enclosed structures with complete walls and roof that include an air management system capable of removing odors and noxious compounds permitted by the Department pursuant to N.J.A.C. 7:27. The building is required to have a minimum setback of 50 feet from the property line of the recycling center.

However, provisions of the regulation also allow a recycling center to operate a Research, Development, and Demonstration (RD&D) project pursuant to N.J.A.C. 7:26-1.7(f) to demonstrate that the specific materials received do not require full enclosure to prevent leachate problems and off-site impacts such as odors from typical food wastes. Based on the results of the RD&D project the Department may issue a general approval to allow other forms of structures or other measures that would be adequate to prevent on and off-site impacts.

When these regulations were promulgated, the provisions appear to have envisioned large-scale compost facilities. No specific provisions were made for micro-scale, small-scale, or medium scale food waste compost facilities that may have lesser impacts to the environment and human health than large, or very large facilities.

3. Charge Questions and Responses

The SRWMP posed the three following charge questions for the Work Group to address. Brief responses from the Work Group are provided here for each charge question. These are intended to be distillations of more in-depth information presented in various sections of this report, to which the reader is also directed.

Charge Question 1: What are the potential impacts to groundwater and air from outdoor food waste composting?

Response

Leachate and runoff from outdoor food waste composting potentially can contain high concentrations of organic matter, nutrients, and other contaminants. Discharge to surface water must be prevented, and depending on the composting material, operations, and site factors, discharge to groundwater may lead to non-compliance with groundwater quality standards. Best management practices (BMPs) have been developed to prevent or mitigate these concerns. Leachate issues are addressed mainly in Section 8.

Potential air impacts from outdoor food waste composting operations include particulate matter, volatile organic compounds, and greenhouse gases (especially methane and perhaps nitrous oxide), but most concern focuses on odors and bioaerosols. Mitigation of these concerns usually involves both BMPs and buffer zones. Air issues are addressed mainly in Section 9, and buffer zones in Section 11. Human health concerns for both workers and nearby residents mainly center on air emissions, particularly of bioaerosols; these are discussed in Section 10.

Both water and air impacts may depend on the materials being composted (addressed in Section 5), composting methods used (Section 6), and the size of the facility or amount of material being handled (Section 12).

Compost product quality is of importance for several reasons, including with respect to potential health concerns, measures of process effectiveness, and as indicators of potential water and air impacts. Testing requirements are discussed in Section 7.

Charge Question 2: What is the best recipe for composting of food waste?

Response

In order to provide for rapid and effective composting while minimizing odors and other problems, it is necessary to adequately satisfy the needs of the microbial community that is responsible for this activity. This requires the balancing of a number of factors, including maintenance of a suitable temperature range, oxygen levels, moisture content, pH, carbon to nitrogen ratio (C/N), and other nutrient concentrations. Mixing various wastes together in appropriate proportions and mixing food wastes with bulking agents can be helpful or necessary in achieving some of these objectives. This is discussed in Section 5.

Charge Question 3: What buffer do you need around these facilities?

Response

Buffer zones around food composting operations may be desirable to mitigate a number of environmental issues, but for this report the focus was on odors and bioaerosols. Some of the related issues are noted above in the response to Charge Question 1, while buffer zones are addressed specifically in Section 11.

4. Work Group Recommendations

a. Although this report focused on outdoor composting, the potential roles of enclosed composting and the use of food waste as animal feed, in producing renewable energy (e.g., anaerobic digestion at water pollution control plants with digesters or in stand-alone facilities), and other forms of recycling and reuse should not be ignored.

b. Composting is a proven technology for conversion of many organic wastes to a useful and environmentally beneficial product. However, composting sites may also be a source of environmental problems, especially water contamination and odors. For this reason, any proposed facilities should thoroughly document how these issues will be minimized as part of the approval process.

c. Although food waste is a very variable feedstock, in many cases it is too wet. Therefore, a composting facility needs to store sufficient amounts of dry bulking agent (see Section 5).

d. Even though food waste is source-separated, the separation is not 100% efficient and pre- and post-processing measures need to be in place to remove waste materials (Section 5).

e. Outdoor food waste composting operations are likely to generate leachate. Both the amount produced and the concentrations of contaminants present may vary widely depending on the starting materials, processing methods, and site itself. A variety of best management practices must be employed to prevent discharge to surface waters, and to ensure that any discharge to groundwater does not lead to violation of groundwater quality standards (Section 8).

f. Food waste and food waste composting are prone to odor generation. This depends on many factors related to the starting materials, processing methods, and site itself. A suite of best management practices must be employed by a facility to minimize odor problems (Section 9).

g. Based on both dispersion models and experience, recommended buffer zones for medium to large outdoor food waste composting facilities, based on odors and *Aspergillus fumigatus* bioaerosols, may be 1000-2000 feet or more. While it is possible that best management practices may reduce these distances for some sites, this is an indication of why future large-scale food waste composting facilities in most parts of New Jersey will need to be enclosed (Section 11).

h. Very small composting operations pose much less risk of odor, leachate, and other environmental problems, and offending materials are more easily removed if necessary. This warrants application of reduced permitting conditions, including the possibility of exemption from most requirements, as is practiced in some other states (Section 12).

i. The two outdoor composting methods with a long history are windrowing and aerated static pile (ASP). Windrowing has the operational advantage of simplicity and provides more frequent turning. ASP is usually expected to produce less leachate, can be operated in a way to generate less odor, and may emit fewer bioaerosols due to the decreased turning; however, the control of an ASP is more complex. Some newer approaches provide full or partial covering of the composting material, which may reduce leachate and odor release. To promote innovation, it is recommended that none of these types of operations be prohibited at this time, but rather that all proposals be required to document how they will meet the environmental requirements of the site (Section 6).

j. If finished compost is to be used off-site, some product testing is recommended. Since the analytical testing methods of the US Composting Council are well accepted in the composting community, it is suggested they form the basis of the analyses to be used (Section 7).

k. The intended use of the compost should be clearly defined prior to the selection of the technology to be chosen. Early input from compost users will help to produce a marketable product where that is a goal.

l. To date, the human health risk associated with exposure to composting of organic wastes seems to be low for most people, and no serious outcomes have been reported associated with food waste composting. However, it is logical to anticipate an increased risk of infection in immunocompromised individuals, and the pros and cons of active or passive surveillance or some type of public notification can be considered. For worker protection, keeping materials moist will reduce production of bioaerosols and thus mitigate risk of respiratory and dermal conditions. Measures to inform or exclude from the workplace those who are immunocompromised can be considered. Best management practices and buffer zones are needed to protect individuals at higher risk. The threat to people who have any degree of immunosuppression needs further exploration (Section 10).

m. Although Work Group members may not be aware of all of the steps that will be part of the formal rule-making process in this case, we applaud previous DEP efforts to involve stakeholders, and also the inclusion of training requirements for facility operators.

n. Because food waste is so variable, and because some aspects of composting can be very material and situation specific, there is likely to be little peer-reviewed scientific literature available that is directly applicable for consideration of a proposed operation, especially for small-scale outdoor composting. In Europe, composting of source separated food and yard waste, mostly at medium and large scale, has been practiced for several decades and this experience can inform implementation of food waste composting in New Jersey. Much of the information included in this report is based on reasonable inference from similar composting practices, and some is from the gray literature. Thus there will continue to be a need for research on food waste composting in New Jersey, and it is recommended that NJDEP considers conducting or sponsoring such research. Topics identified include:

    1) Monitoring of environmental impacts of small-scale composting sites.
    2) Odor and bioaerosol dispersion modeling that can be implemented at New Jersey composting sites.
    3) Human health impacts of composting on immunocompromised residents.
    4) Connecting leachate generation forecasting models from composting operations with surface and groundwater quality models.
    5) Establishing pathogen, parasite, and weed seed destruction efficiencies and bioaerosol emission rates for food waste composting operations.

<u>5. Nature of Food Waste, Composting, and Composting "Recipes"</u>

5.1 Definitions of food waste

Defining food waste can be challenging, as there is no universally accepted definition. Does it include materials on-farm, during storage and processing, in transport, and/or from supermarkets, restaurants, institutions or households? The United Nations Environment Program (UNEP) defines food waste as "food that completes the food supply chain up to a final product, of good quality and fit for consumption, but still doesn't get consumed because it is discarded, whether or not after it is left to spoil or expire. Food waste typically (but not exclusively) takes place at retail and consumption stages in the food supply chain" (UNEP, 2019). Based on this definition the following stages of the food supply chain are included in this report: final part of the manufacturing/processing stage, distribution, wholesale, retail, out-of-home consumption (e.g., restaurants, schools, hospitals) and home consumption. On-farm wastes, handling and storage and the major portion of the manufacturing/processing stage are outside this scope.

The UNEP definition excludes the inedible portion of the food such as peels or rinds, chicken bones or corncobs. For the purpose of this report, the definition is expanded and includes the inedible portion. This seems more appropriate for this report as edible and inedible portions of food products are typically disposed of and composted together. This also follows the United States Environmental Protection Agency's (USEPA) definition of food waste as "food such as plate waste (i.e., food that has been served but not eaten), spoiled food, or peels and rinds considered inedible that is sent to feed animals, to be composted or anaerobically digested, or to be landfilled or combusted with energy recovery" (USEPA 2019a). Solid food waste discharged to the sewer via the garbage disposal in the kitchen sink is included in the scope of this report, if collected for composting.

Food waste to be composted might also be mixed with other compostable products (e.g., paper plates, napkins). If compostable products are collected together with the food waste, it needs to be ensured they do not negatively affect pre-processing in the composting facility and are decomposed while at the composting facility. The inclusion of biodegradable plastic products also needs to be assessed carefully, because they are difficult to distinguish from non-degradable plastics during pre-processing and because they might not degrade in smaller composting facilities that are the size of small-scale backyard composters (Körner et al., 2005, Greene and Tonjes, 2014), nor degrade at a sufficient rate to be eliminated during processing.

5.2 Challenges with food waste composting

Food waste is a challenging composting feedstock because it is "a highly heterogeneous material with a high moisture content, high organic to ash ratio, and an amorphous physical structure" (Cerda et al., 2018). The variability is such that generalizations about it are difficult. For example, individual food wastes may have a high (e.g., carbohydrate or fatty materials) or low (e.g., proteinaceous materials) carbon to nitrogen ratio (C/N); be relatively stable or highly putrescible; be very acidic (naturally containing acids or because they have fermented) or neutral or even alkaline. They are usually wet, or very wet, but could also be too dry. One concern with highly putrescible wastes, such as some food wastes, is that they may be highly odorous already when they arrive at a site. They might have fermented at the source or in the collection bin, which can cause a lag phase during composting delaying the decomposition (Sundberg et al., 2013).

In addition, as source-separation is not 100% efficient, food waste can be contaminated with other waste materials. To separate these the facility needs to be equipped with the appropriate pre-processing equipment (see for example, Chiumenti et al., 2005 or Krogmann et al., 2010).

Leaf composting may typically be done under suboptimal conditions, allowing the extra time required (months) in exchange for reduced processing costs (Strom et al., 1980; Strom et al., 1986; Strom and Finstein, 1994). However, with more putrescible wastes, such as most food wastes, it is usually desirable to provide more nearly optimized conditions in order to achieve a higher biodegradation rate during the composting process so as to quickly destroy the problematic substances, reduce odor generation, and decrease the time the material remains on site (Finstein et al., 1986a, b and 1987a, b, c, d). A primary factor that can interfere with rapid composting is excessive temperatures, which can inhibit or even kill the microorganisms responsible for biodegradation (especially at 150 °F or higher); thus one goal of process control in active composting is preventing such temperatures from occurring. On the other hand, low temperatures, such as can occur in very small piles, can interfere with rapid composting and with achieving pathogen kill and destruction of weed seeds.

5.3 Composting "recipes" or best practices

Moisture content, C/N, and the material structure/substrate porosity are typically adjusted in the initial feedstock, often by mixing different food wastes, or food waste with other materials (often referred to as bulking agents) such as yard waste or woodchips. Various wastes also may be mixed to adjust the pH of food waste (e.g., cranberry fruit with horse manure, Ramirez-Perez et al., 2007).

The optimum moisture content for composting is feedstock specific and varies between 40-70%, with higher optimum moisture contents for feedstocks that are coarser and have higher water holding capacities. If the moisture is too low, decomposition is slowed. Moisture contents above optimum reduce the availability of oxygen, which then favors slower anaerobic degradation accompanied by the formation of odorous gases. During composting, the maximum tolerable moisture content (Bidlingmaier, 1983) of coarser feedstocks (e.g., wood and bark 74-90%) exceeds the tolerable moisture content of feedstocks with less material structure (e.g., paper, 55-65%; food waste and grass, 50-55%). In many cases, food waste is too wet (Table 5-1). The addition of a dry bulking agent such as woodchips, shredded bark, sawdust, or recycled compost is a common practice to lower the initial moisture content. However, this can increase the composting mass substantially.

With the exception of nitrogen, composting feedstocks generally contain enough other nutrients (e.g., phosphorus, potassium, sulfur, calcium, iron, magnesium), including trace nutrients, to sustain the composting process. Very uniform feedstock can create exceptions (e.g., paper is low in phosphorus). Therefore, generally only the C/N is adjusted.

Assuming a C/N of microbial cells of 5/1 (Vaccari et al., 2006) and assuming 20% of the carbon is used for the biomass and 80% for energy, the initial C/N of the composting feedstock should be 5 * (80+20)/20 = 25. Of great importance is the actual availability of the carbon and nitrogen. With the exception of keratin (structural protein, for example in hair) and a few similarly resistant components, nitrogen is considered available. However, carbon in lignin, some aromatics and cellulose embedded in lignin is resistant to degradation. Therefore, a suitable C/N at the beginning of the composting process is between 25 and 30 for most wastes. For woody feedstocks containing a considerable portion of lignin, a C/N of 35-40 is considered optimum (Golueke, 1977). Wastes with lower and higher C/N can be composted, but a too high C/N slows microbial degradation while a too low C/N results in the release of nitrogen as ammonia, to the air and/or in leachate. Especially if anaerobic conditions develop (with attendant low pH from production of organic acids via fermentation), low C/N can also lead to the release of amines, some of which have especially unpleasant odors (e.g., putrescine, cadaverine). The C/N of food waste is more often too low (Table 5-1), requiring the addition of a carbon source (typically as the bulking agent).

Regardless of the feedstock or the selected technology, a minimum free pore space of 20-30% (Haug, 1993) to 35-50% (Chiumenti et al., 2005) is recommended. The free air space is needed to ensure sufficient supply of oxygen to the waste. Particle sizes and particle size distributions, as well as the structural strength of the material, determine the free air space. Large, firm and irregular shaped particles lead to more free-air space. Food waste typically has a poor material strength causing free air space to collapse under the pressure of the overlying material. Typically, a bulking agent reducing the moisture content also increases the free air space. Lambert and Neubauer (2015) additionally note that sufficient supply of oxygen is important to reduce methane emissions, and recommended that source-separated food and yard waste from urban areas in Austria be mixed with the same volume of bulking agent (i.e., about 50% by volume, which is about 25% bulking agent by mass of the final mixture).

The addition of a bulking agent and/or recycled compost can help to adjust the pH. Adjusting the pH with lime (granulated limestone) should be performed with care, because it can result in increased ammonia emissions (Amlinger et al., 2005) for low C/N wastes.

Table 5-1. Moisture, N, C/N, and material structure of various food wastes and bulking agents

	Moisture (% wet weight)	N (% dry weight)	C/N	Material structure[1]	Reference
Food wastes					
Food waste	76	1.9	22	Poor	Krogmann et al. (2010)
Source-separated food and yard waste					Krogmann et al. (2010)
- downtown (no yards)	64-77	1.2-2.3	17-27	Poor	
- single-family homes	57-71	1.1-2.0	15-23	Good to Poor	
Corn cobs	9-18	0.4-0.8	56-123	Good	Rynk (1992)
Fruit wastes	62-88	0.9-2.6	20-49	Poor	Rynk (1992)
Vegetable produce	87	2.7	19	Poor	Rynk (1992)
Vegetable wastes		2.5-4	11-13	Poor	Rynk (1992)
Vegetable food processing wastes	86-91	2.8-7.0	7-14	Poor	Rogers et al. (2001)
Coffee grounds	6.2	1.4	32		Rogers et al. (2001)
Tomato skins and seeds	86	1.7	31		Rogers et al. (2001)
Cranberry skins and rice hulls	53-61	1.1-1.2	44-52		Rogers et al. (2001)
Fish waste (gurry, racks and so on)	50-81	6.5-14.2	3-5	Poor	Rynk (1992)
Mixed slaughterhouse waste		7-10	2-4	Poor	Rynk (1992)
Bulking agents					
Wood (e.g., chips, shavings)					Rynk (1992)
- softwood		0.04-0.23	212-1313	Good	
- hardwood		0.06-0.11	451-819	Good	
Straw	4-7	0.3-1.1	48-150	Good	Rynk (1992)

[1] Based on Bidlingmaier (1983) or best professional judgement.

5.4 Composting of meat products

Composting of meat products, which can be very wet, high in nitrogen, and highly putrescible, is of concern because of the potential for attraction of pests, production of odors, and presence of pathogens. There is more of an issue if meat by-products from meat processing plants are composted compared to predominantly plant based waste containing some meat products. Small-scale backyard composters do not reach high enough temperatures throughout the composting material to ensure sufficient pathogen reduction (Storino et al., 2016). However, this could be different at large-scale facilities. Frank-Whittle and Insam (2013) reviewed treatment alternatives for slaughterhouse wastes, including composting, and the inactivation of pathogens. They concluded that under stringent management, composting of slaughterhouse wastes would not be expected to pose a risk to human and animal health; however, some pathogens, such as prions (e.g., the infectious agent for mad cow disease) and some spore-forming bacteria might survive composting. Open facilities for meat by-products require special considerations (Vidussi and Rynk, 2001). Some guidance can be based on experience with composting of animal mortalities on farms (Berge et al., 2009).

6. Outdoor Composting Methods

The objective of a composting facility is the production of high-quality compost under controlled conditions, with minimal adverse effects on the environment, at reasonable costs. A composting facility for food waste consists of areas for tipping the food waste; pre-processing of the incoming waste; post-processing of the compost; storage of bulking agents, final compost and disposal residues; and for composting itself, including the active stage and potentially a slower "curing" stage. While this report focuses on the composting portion of the facility, all areas can contribute to environmental impacts to varying degrees, and therefore, need to be considered when designing and operating a composting facility.

There are two ways of minimizing environmental impacts, such as odorous emissions, from the composting area: 1) control of the microbial degradation, and 2) installation of technical control measures. To enhance the composting process, independently of the feedstock, the rate of microbial decomposition is usually increased by at least partial optimization of the composting process. The main influencing parameters are typically controlled based on an understanding of the growth conditions of the decomposing microorganisms. The parameters considered, as indicated above, include:

- Biodegradability
- Moisture content
- Oxygen content, material structure, particle size, and aeration
- Temperature
- Nutrients (mainly C/N)
- pH

6.1 Outdoor versus enclosed composting

There are open (outdoor), enclosed (in-vessel) and partially enclosed composting facilities. Enclosed and partially enclosed facilities are generally superior with regard to odorous emissions and leachate/runoff control but are more complex, costly, and energy intensive, and are not covered here. However, summaries can be found in Chiumenti et al. (2005) and

Krogmann et al. (2010). In enclosed facilities the compost is not exposed to precipitation, although condensate might be produced in condensers or on colder building surfaces such as roofs and walls. The semi-enclosed facility in Cloppenburg-Stapelfeld, Germany, demonstrated that a semi-enclosed composting facility can be operated without discharges of leachate and runoff through partial enclosure, a roof over the curing area and use of condensates in the process (Krogmann et al., 2010). Regarding the release of the greenhouse gasses CH_4 and N_2O, Lampert and Neubauer (2015) suggested that process optimization is more important than enclosure.

In open systems the gaseous emissions of the composting process escape, in most cases without control, to the surrounding environment. Layers of finished compost acting as a biofilter or synthetic covers can provide some degree of control of gaseous emissions. A distinction among open systems is if the compost is moved periodically after placement or not. In static systems the compost is not moved, while in agitated systems the compost is at rest most of the time, but is moved or turned at intervals for homogenization, fluffing and to a lesser extent for aeration and perhaps some control of temperature. Open composting technologies include windrows, aerated static piles with compost covers, and aerated static piles with synthetic covers (e.g., plastic bag/sleeve, semi-permeable sheeting, or "compost fleece"). The synthetic covers provide essentially a temporary mobile enclosure for the composting area.

Another concern with composting in general, and perhaps food waste composting in particular, is the attraction of vermin, including disease vectors. The range of possible examples include rats, mosquitos (in ponded water), and seagulls. In some cases these may be more difficult to control with outdoor composting.

A comparison of different open composting systems is provided in Table 6-1. The following subsections look at each type in more detail.

Table 6-1. Comparison of various open composting systems (best professional judgement if not stated otherwise[a])

	Windrows	Aerated static piles (compost cover)	Aerated static piles (membrane cover)
Land area [acre/ton] (Kranert, 2000)	0.000269-0.00056	0.000224-0.000493[b] (0.00009-0.000179)[c]	0.000224-0.000493[b] (0.00009-0.000179)[c]
Odor control	Size of pile, compost fleece, turning when favorable wind direction	Compost cover providing some odor control	Membrane providing some odor control
Leachate control	No, some control with compost fleece	Some control due to higher evaporation	Membrane provides some control
Oxygen control	No, some control through pile size	Included in temperature control	Yes
Temperature control	No, some control through pile size	Yes	No
Complexity	Low	Moderate	Moderate
Main composting / curing time [weeks]			
Krogmann et al. (2010)	12-20	3 / 6-8[d]	8 / 4-12
Montgomery County (2018)	16-20 / 2-4	8-10 / 4-6	8-10 / 4-6
Goldstein (2015)			8 / 10-12
Costs (Montgomery County, 2018)	Lowest capital costs, medium operating costs	Medium capital, low to medium operating costs	Low to medium capital, medium operating costs

[a] Based on best professional judgement, because not found in the literature. More documentation of actual designs and case studies is needed.

[b] Composting with process control, 13,000 ton/yr.

[c] Composting with process control, 55,000 ton/yr.

[d] Biosolids.

6.2 Windrow composting

Windrows, which are elongated piles, can be used for the entire composting process or for curing only. Windrowing varies in terms of pile size, turning equipment, and turning frequency, but at larger-scale usually requires frequent turning by specialized equipment. Windrows are naturally ventilated by diffusion and convection. A simple, but not very effective turner is the front-end loader, which is often used in small-scale facilities.

Agitation speeds up microbial activity by breaking up particles, thereby exposing fresh surface area to microbial attack, and the mixing brings microorganisms into contact with undegraded substrates. The effect of turning on the oxygen supply of the windrow is not very substantial unless the pile is turned almost constantly. In general, turning also provides poor control over temperature. The heat released from the increased microbial activity after turning causes a rapid increase in temperature, often surpassing the temperature prior to turning, and also quickly depletes oxygen (Miller et al., 1989). If temperatures increase above 65-70ºC, decomposition is slowed down, and if temperatures increase to 80ºC, it nearly stops (Miller et al., 1989) and especially odorous compounds (e.g., pyridine and pyrazine) can be released due to chemical, non-biological reactions (Mayer, 1990). Smaller pile sizes can increase oxygen levels and decrease temperatures to some degree (Strom et al., 1980).

The turning frequency is decreased from a maximum during the initial phase, which has the highest rates of degradation and emission, and during which most pathogen reduction takes place, to less often as the material becomes stabilized. During curing turning is often omitted, although Amlinger et al. (2005) also recommended turning during curing to ensure low odor emissions. In most cases, higher turning frequencies lead to a decrease in processing time but also to an increase in operating costs. Amlinger et al. (2005) recommended an initial turning frequency of every 3-4 days to lower methane emissions. However, frequent turning can increase ammonia and nitrous oxide losses (Amlinger et al., 2009). To achieve pathogen reduction goals for unrestricted compost use, state regulations generally follow 40 CFR Part 503 (USEPA, 2018) pathogen reduction requirements for biosolids (for windrow composting, 5 turnings during 15 days with temperatures above 55 ºC).

The turning equipment and the aeration type (natural versus active) determine the windrow dimensions such as cross-sectional shape (e.g., triangle or trapezoid), height, and width. For example (Kern, 1991), the base of a naturally ventilated, triangular windrow of source-separated food and yard waste can vary from 3.0 – 4.0 m (10-13 ft) and the height between 1.0 – 2.5 m (3-8 ft). Amlinger et al. (2005) recommended an initial pile height of 1.5 m to lower odor emissions. A cover with a layer of compost or wood chips or a compost fleece can reduce odor emissions further, although the authors indicated that there are few studies assessing the effectiveness of this measure and therefore no final recommendation was given (see also discussion on synthetic covers below). For frequently turned, naturally ventilated windrows of source-separated food and yard waste, processing times of 12-20 weeks were reported (Kern, 1991). If turned very frequently (7 times per week initially decreasing to 2 times per week) processing times can be less than 12 weeks (Amlinger et al., 2005). Less often, windrows are aerated by forced or vacuum-induced aeration similar to aerated static piles (see discussion on active aeration below). With active aeration 2.5 – 3.0 m (8-10 ft) pile heights are feasible. Strom and Finstein (1994) emphasized that even for leaves-only composting, pile height should not exceed 6 feet to avoid overheating and excessive odors.

6.3 Static pile composting

The lack of agitation in static pile composting requires the maintenance of adequate porosity over an extended period even more so than in windrows. In most cases, the static pile has the shape of a truncated pyramid. As a modification, the feedstock can be stacked in open composting cells; to compensate for vertical moisture and temperature gradients in the piles, the composting material in this system is moved from one cell to another. Chiumenti et al. (2005) pointed out that an unaerated static pile in the shape of a truncated pyramid is not aerated as well as a windrow.

In the United States, the aerated static pile is one of the most common biosolids (treated sewage sludge) composting technologies and is also implemented in food waste composting. Typical dimensions are between 12 m and 15 m (39-49 ft) at the base with a height of 3 m (10 ft). The technology was developed in 1970 in Beltsville, MD, by the Agricultural Research Service of the U.S. Department of Agriculture. Piles were covered with a layer of finished compost to prevent heat loss from the upper layer and provide a minimum-level of odor treatment of gaseous emissions (USEPA, 1981). The timer-controlled blowers maintained an oxygen level of 5-15%. However, unfavorable temperatures (180 °F) in the static pile resulted in the development of the Rutgers process (Finstein et al., 1986a), which adopted temperature-controlled blowers (in most cases the temperature is below 60ºC in the pile). In the initial and final composting phases, the temperature feedback needs to be overridden by a timer to ensure minimum aeration if the temperatures in the pile are below the set point (Lenton and Stentiford, 1990). The aeration of the initial process in Beltsville was vacuum induced while the Rutgers process used forced aeration once it was realized that temperature control could not be achieved in vacuum mode. Discussions of ventilation direction are available in Finstein et al. (1986a and 1987a, b, c, d). Typical processing times for sludge in aerated static piles are 21 days followed by 6-8 weeks of curing in windrows, but shorter times may be feasible (Finstein et al., 1983).

Aerated static piles, if properly controlled using temperature feedback with forced aeration to increase composting rate, provide more rapid decomposition for most wastes. They also decrease leachate generation because temperature feedback control utilizes evaporative cooling to maintain optimal temperatures, and the total aeration demand is 5-10 times higher for cooling than for the stoichiometrically needed oxygen (Krogmann et al., 2010). Due to the moisture gradient established, aerated static piles with forced aeration are on the dry side in the lower part of the pile (see below). It should be noted (Finstein et al., 1983; Finstein et al., 1986a) that temperature feedback is really only effective if positive pressure ventilation (blowing air into the middle of the pile), rather than vacuum (drawing air from the middle of the pile) is used. The idea that vacuum aeration allows for better odor control is a misconception; it is not usually possible to adequately control temperature with the much less efficient vacuum approach, leading to greater odor production and less rapid decomposition of odorous compounds. A better approach is to use forced pressure aeration, but to cover the pile with a thin layer of finished compost that can then serve as a biofilter for odor control (Finstein et al., 1986a). In this biofilter layer, odorous compounds can be partially adsorbed to the compost particles, decomposed, or dissolved in the condensate in the upper cooler compost cover. Other disadvantages of vacuum induced aeration are a higher energy consumption and a wet compost layer at the lower part of the pile compared to a pile with forced aeration. The wet layer can cause considerable odor emissions when the compost is moved (Amlinger et al., 2005).

One disadvantage of an aerated static pile is that the composting materials are not routinely mixed during this phase of the operation. This allows development of substantial gradients of temperature and moisture, preventing achievement of near optimal conditions uniformly throughout the pile. Due to the moisture gradient, the lower portion of the pile can dry out, extending the processing time. In Austria this was found to be a major pitfall of aerated static piles if they were not controlled carefully (Amlinger et al., 2005). It is also possible for channeling (rather than good distribution) of air to occur. Overall, this usually makes it necessary to control the aeration carefully and incorporate a second, or curing stage.

6.4 Composting using synthetic covers

Synthetic covers include plastic bags/sleeves such as EcoPOD® and EURO bagging technologies, semi-permeable sheeting such as GORE-TEX®, and compost fleeces such as ComposTex®. These covers can overcome or mitigate some of the disadvantages of open composting methods (odors, run-off, leachate). However, they also may add to the cost of an operation, and there may be limited peer-reviewed literature available for a specific proprietary product.

Compost fleece (e.g., ComposTex®, a UV resistant gas permeable polypropylene fabric) is used as a temporary measure to reduce odor emissions and keep compost dry, especially later in the composting process during times of lower evaporation. Amlinger et al. (2009) summarized the functions of compost fleeces as conservation of moisture in the windrows due to condensation, diversion of precipitation, and prevention of dry windrow surfaces, while still allowing gas exchange, resulting in more homogenous composting. In Austria, compost fleeces or roofs are recommended during heavy rain events if the annual precipitation exceeds 1000 mm (39.4 in – all parts of New Jersey typically receive more than this) and the windrows are not positively aerated, to avoid increased odor emissions caused by high moisture levels (Amlinger et al., 2009). Paré et al. (2000) confirmed leachate reduction during the composting of crucifer and carrot residues mixed with sawdust and straw in Quebec, Canada, when covered with a ComposTex® fleece. Automatic compost fleece winding equipment attached to the turning machine is recommended for larger facilities.

Plastic bags/sleeves and semi-permeable sheeting technologies have the same benefits as compost fleeces, but also allow the control of temperature and oxygen levels in the covered piles. Semi-permeable sheeting consists of three layers, a semi-permeable polytretrafluoroethylene (PTFE) membrane sandwiched between two UV-stable polyester fabric layers (Kühner, 2001). The membrane is gas and water vapor permeable, but impermeable to liquid water because of the larger size of the rain drops. Water vapor also condenses on the inside of the sheeting and odorous compounds are partially dissolved in the condensed water, which drips back onto the composting material. Oxygen and temperature are measured, and the process is controlled based on oxygen levels. Some of the temperatures seem to be above 75ºC for long periods of time (Anon. 2017). A study investigating the detrimental effect of the high temperatures in this case was not found, but such temperatures are known to be problematic (e.g., Finstein et al., 1987a). One of the scarce studies investigating semi-permeable membranes (Kühner, 2001) showed a reduction in odor emissions of 97% compared to open windrow systems. The odor emissions were measured by an olfactometer (measuring the dilution of odorous air with odorless air at which 50% of panelists smell something and 50% do not). However, the author pointed out that additional simple measures to reduce odors during curing such as smaller piles are needed to maintain the benefit of reduced odor emissions during composting under covers.

While the semi-permeable covers help reduce odor emissions and leachate/runoff, they do not guarantee problem-free operation of a composting facility, if not operated correctly, as proven by the closing of the Peninsula operation in Delaware (BioCycle, 2014; Seldman, 2014). Among other issues, the facility did not use sufficient amounts of bulking agents, nearby neighbors were affected by odor emissions, and the compost contained visible contaminants.

A modification of coverage with sheeting is an aerated pile in a patented plastic bag system. Plastic bags/sleeves (e.g., Avidov et al., 2018) allow the collection and treatment of gaseous emissions, although external treatment in a biofilter is generally not implemented. These polyethylene bags/sleeves were originally used as silage bags and are modified for composting application. Composting in the bags for 8 weeks is followed by 1-3 months of curing (Chiumenti et al., 2005). There is much less experience with bag composting. Avidov et al. (2018) noted the likelihood that use of polyethylene sleeves would reduce leachate, although no rain occurred during their trial.

6.5 Management

No matter the scale and technology, proper management and quality control is key for a well-operated composting facility. This includes pre- and post-processing equipment to remove waste materials and the availability of sufficient amounts of bulking agents. The most suitable technology for a given situation depends on the location and the capacity of the facility as well as the waste material. All-weather operation needs to be possible; leachate and air emissions need to be handled. While aerated static piles and covered aerated static piles might reduce odors and leachate, there are still emissions as material needs to be moved, there are gaseous emissions from the aerated static piles, and the operation of aerated static piles and covered aerated piles is more complex (e.g., the aeration can dry out the unfinished composting material). Best management practices and guidelines on how to operate composting facilities and control odor emissions can be found in Coker (2016) and Müsken (2001). While there are comparisons between outdoor and in-vessel systems in Europe, side-by-side comparisons of various open composting systems are limited.

After composting is completed, the material is screened for particle size and contaminants, and may be bagged. Screening may be a major source of bioaerosols and/or dust. With sludge composting, woodchips added as a bulking agent are typically recovered for reuse during screening; this is a major source of *Aspergillus fumigatus* spores (Millner et al., 1977) that may or may not be relevant for specific food waste composting operations.

7. Compost Product Testing Requirements

There are no national testing requirements for composts from source-separated food wastes in the US, which is different from many other countries (Brinton, 2000; Harrison, 2003; Bernal et al., 2017); instead, testing requirements vary by state. Bernal et al. (2009) define compost as a "stabilised and sanitised product of composting, which has undergone an initial, rapid stage of decomposition, is beneficial to plant growth and has certain humic characteristics". Based on this definition testing requirements include plant nutrient concentrations and indicators of organic matter humification, pathogen reduction, and maturity (Bernal et al., 2017). To address environmental and safety issues, testing requirements include visual contaminants and chemical pollutants. Further testing requirements depend on the intended use of the compost such as available nutrients for agricultural fields or water holding capacity for growth medium mixes (Bernal et al., 2017).

The US Composting Council's Seal of Testing Assurance Program (STA) certifies composts and requires the analysis of the following parameters (US Composting Council, 2019):

pH
soluble salts
nutrient content (total N, P_2O_5, K_2O, Ca, Mg)
moisture content
organic matter content
bioassay (maturity)
stability (respirometry)
particle size (report only)
pathogen indicator (Fecal Coliform or *Salmonella*)
trace metals (Part 503 regulated metals)

As an example of state regulations, New York requirements are given in Table 7-1 (NYSDEC, 2019a, b). These are similar to the analyses required for the US Composting Council's STA certification.

Table 7-1. New York State testing requirements (NYSDEC, 2019a, b):

Parameters for Analysis,*and Limits, where specified (mg/kg dry weight)	
Total Kjeldahl Nitrogen	Arsenic (As ≤ 41)
Ammonia	Cadmium (Cd ≤ 10)
Nitrate	Chromium (total) (Cr ≤ 1000)
Total Phosphorus	Copper (Cu ≤ 1500)
Total Potassium	Lead (Pb ≤ 300)
pH	Mercury (Hg ≤ 10)
Total Solids	Molybdenum (Mo ≤ 40)
Total Volatile Solids	Nickel (Ni ≤ 200)
	Selenium (Se ≤ 100)
Fecal coliform or *Salmonella* sp. bacteria	Zinc (Zn ≤ 2500)

* Analyses to be done 2-12 times/yr, depending on size of facility (2 times if < 5 yd^3/d).

In New York State, the number of parameters to be analyzed can be reduced after two years. Compared to the US Composting Council's STA requirements, no maturity test is specified, but how maturity is determined needs to be outlined. Pathogen and vector attraction reduction requirements need to be met as well. There are also limits for visible contaminants. No dilution with bulking agents is allowed and an analysis of the bulking agents might also be necessary. Furthermore, information about compost uses needs to be provided.

As another example, Washington State also specifies testing and includes limits (WAC, 2018a). As can be seen in Table 7-2, these are very similar to the ones from New York State. They omit chromium, and do not include the fertilizer (NPK) tests, but do add plastic and sharps as contaminants of concern. Several of the limits are also set at lower values. Although total solids is not included, it must be determined in order to report the other test results on a dry weight basis.

Table 7-2. Washington State testing for compost (Source: WAC, 2018a).

Parameters	**Limit** mg/kg dry weight (unless noted)
Arsenic	20
Cadmium	10
Copper	750
Lead	150
Mercury	8
Molybdenum	9
Nickel	210
Selenium	18
Zinc	1400
Physical contaminants[1]	1% by weight total, not to exceed 0.25% film
Sharps	0
pH	5 - 10 (range)
Biological stability[2]	Moderately unstable to very stable
Fecal coliform OR *Salmonella*[3]	< 1,000 MPN/g dry solids < 3 MPN/4 g dry solids

[1]A label or information sheet must be provided with compost that exceeds 0.1% film plastic. See WAC 173-350-220 (6)(f)(iii)(D)(I).

[2] Tests for biological stability must be done as outlined in the United States Composting Council Test Methods for the Examination of Composting and Compost unless otherwise approved by the jurisdictional health department.

[3] Test for either fecal coliform or *Salmonella* (MPN = most probable number).

For comparison, the compost certification system in Germany has several requirements regarding pathogen reduction. First, the chosen composting system needs to be one of about 30 approved and tested composting systems (BGK, 2010); second, monitoring needs to ensure certain time – temperature requirements (at least a certain temperature for at least a specified amount of time) are met; and third, *Salmonella* and weed germination thresholds need to be met (BGK, 2017).

The European Composting Network (ECN, 2018) has developed a certification program for compost that includes a “minimum set of compost properties for declaration” and “precautionary limits”, as shown in Tables 7-3 and 7-4. The limits on potential toxic elements in this document are based on Amlinger et al. (2004).

Table 7-3. ECN (2018) minimum set of compost properties for declaration.

Quality criteria	Parameter	Dimension	Appraisal
Soil improvement	Organic matter	[% DM]	≥ 15 %, declaration
	Liming value (CaO)	[% DM]	declaration
Fertilizing properties	Nitrogen (N) total	[% DM]	declaration
	Phosphorus (P) total	[% DM]	declaration
	Potassium (K) total	[% DM]	declaration
	Magnesium (Mg) total	[% DM]	declaration
Material properties	Maximum particle size	[mm]	declaration
	Bulk density	[g/l FM]	declaration
	Dry matter	[% FM]	declaration
	Salinity / El. conductivity	[mS/m]	declaration
	pH value		declaration
Biological parameters	Aerobic biological activity		declaration
	Plant response[1)]		declaration

[1)] The declaration of plant response is only necessary if the compost is used as mixing compound in growing media.

Table 7-4. ECN (2018) precautionary limit values.

Precautionary quality criteria	Parameter	Limit value
Hygiene	Salmonellae	Absent in 25 g dry matter
Undesired ingredients and properties	Impurities (content)	≤ 0,5 % dry matter
	Weed seeds	≤ 2 seeds per liter
Inorganic pollutants	Lead (Pb)	130 mg kg^{-1} dry matter
	Cadmium (Cd)	1.3 mg kg^{-1} dry matter
	Chromium (Cr)	60 mg kg^{-1} dry matter
	Copper (Cu)[1)]	300 mg kg^{-1} dry matter[2)]
	Nickel (Ni)	40 mg kg^{-1} dry matter
	Mercury (Hg)	0.45 mg kg^{-1} dry matter
	Zinc (Zn)[1)]	600 mg kg^{-1} dry matter[2)]

[1)] Copper (Cu) and Zinc (Zn) are also considered as trace elements. Values exceeding 110 mg Cu kg^{-1} dry matter and 400 mg Zn kg^{-1} dry matter must be declared.

[2)] These values represent orientation thresholds.

It may be noted that some of the limits (e.g., for cadmium) differ substantially among different jurisdictions. This is also clear in a table from Boldrin et al. (2011), as shown in Table 7-5. European limits are seen to differ from country to country, but in general are much more restrictive than those for Texas (sometimes by an order of magnitude or more), as a representative of the USA. Our Work Group is reporting these various values without making a specific recommendation as to which are more appropriate for New Jersey because this exceeds the scope of this document. However, we do note that food waste compost in Europe typically meets their stricter standards (Boldin et al., 2011). Also, the regulations in the USA tend to be based on the 1985 recommendations for sewage sludge/biosolids. Although they were risk-based, concerns have been expressed, considering newer information, about their applicability for all soils and situations in New Jersey (Krogmann et al., 2001; Harrison and Krogmann, 2007). It is recommended that these values be revisited if food waste composting becomes a more common practice in the State.

Table 7-5. Comparison of heavy metal limits in compost (Boldrin et al., 2011).

Table 9.3.7 Heavy metals limits for some compost standards (mg/kg dm), from Hogg et al. (2002). Hogg, D., Barth, J., Favoino, E., Centemero, M., Caimi, V., Amlinger, F., Devliegher, W., Brinton, W. and Antler S. (2002): Comparison of compost standards within the EU, North America and Australasia. Waste and Resources Action Programme, WRAP, Banbury, UK.

Country	Regulation	Cd	Cr_{tot}	Cr(VI)	Cu	Hg	Ni	Pb	Zn	As
Austria	Compost ordinance: Quality Class A+ (organic farming)	0.7	70	—	70	0.4	25	45	200	—
	Compost ordinance: Quality Class A (agriculture; hobby gardening)	1	70	—	150	0.7	60	120	500	—
	Compost ordinance: Quality Class B (landscaping; reclaimed land) limit value	3	250	—	500	3	100	200	1800	—
	Compost ordinance: Quality Class B (landscaping; reclaimed land) guide value	—	—	—	400	—	—	—	1200	—
Germany	Bio waste ordinance (I)	1	70	—	70	0.7	35	100	300	—
	Bio waste ordinance (II)	1.5	100	—	100	1	50	150	400	—
Netherlands	Compost	1	50	—	60	0.3	20	100	200	15
	Compost (very clean)	0.7	50	—	25	0.2	10	65	75	5
EC	Draft W.D. biological treatment of biowaste (class 1)	0.7	100		100	0.5	50	100	200	
	Draft W.D. biological treatment of biowaste (class 2)	1.5	150		150	1	75	150	400	
	2092/91 EC – 1488/98 EC (organic farming)	0.7	70	0	70	0.4	25	45	200	—
UK	UKROFS 'Composted household waste'	0.7	70	—	70	0.4	25	45	200	—
	Composting association quality label	1.5	150		200	1	50	150	400	
USA	Texas TNRCC Grade 1 compost	16	180	—	1020	11	160	300	2190	10
	Texas TNRCC Grade 2 compost	39	1200	—	1500	17	420	300	2800	41

The fecal coliform analysis is probably not an appropriate indicator for pathogen levels in food waste compost (Doyle and Erickson, 2006). *Salmonella* is only a good indicator if it is known that the food waste contained *Salmonella* (Brinton et al., 2009). Brinton et al. (2009) suggested that maybe *Escherichia coli*, *E. coli* O157:H7, fecal streptococci, *Listeria* spp., and *Clostridium perfringens* might be better for compost made from manure and food waste. They also found correlations between *E. coli* and fecal coliforms and the sum of the other indicators and recommended further investigations are needed.

It may be reasonable to assume that with regard to pathogens, composting of food waste represents no greater hazard than composting of sewage sludge (biosolids). Thus the relevant Federal 40 CFR 503 regulations for sewage sludge (USEPA, 2018) have been adopted in many cases for composts produced from a wide variety of other waste materials (Gurtler et al., 2018). Tetra Tech, Inc. (2002) considered use of these regulations appropriate for food wastes, and examined fecal coliform and *Salmonella* spp. indicator reductions, time-temperature protocols, and vector attraction reduction requirements; all were found to be achievable with low level technology. While coliforms and *Salmonella* spp. may not be especially appropriate indicators for food waste, the time-temperature relationships were developed based on work by Burge et al. (1981) and are applicable for virtually all pathogens (one possible exception is prions). They also would be appropriate for other animal and plant pathogens and weed seeds.

Stability indicates that the compost is resistant to further microbial activity, while maturity means that it is ready for its specific end use (Wichuk and McCartney, 2010), which often refers to a lack of phytotoxicity. The California Compost Quality Council (2001) conducted a study comparing various maturity and stability tests. To determine the level of maturity and stability the study recommends testing of the C/N ratio of the compost, which should be < 25, one test from a list of stability tests, and one test from a list of maturity tests. The Solvita® test by Woodsend Laboratory combines two tests, one from each list.

The testing methods of the US Composting Council are well accepted in the composting community. Therefore, it is suggested to base the sampling and analytical methods on the "Test Methods for the Examination of Composting and Compost" (TMECC, 2002).

8. Leachate

Outdoor composting poses concerns for leachate generation, potentially leading to discharges to surface or groundwater. As is true with the other environmental considerations for outdoor food waste composting, the risk depends on the types and quantities of materials being composted, the composting methods and practices being used, and the site itself. Leachate ponding may also promote mosquito breeding and odor production.

The differences in food wastes being composted in turn may lead to leachates with very different properties. For example, high C/N wastes may produce leachates in which the major concern is biochemical and chemical oxygen demand (BOD and COD), while low C/N wastes may leach high concentrations of nitrogen, probably much of it in the form of ammonium. (Nitrate may also be released, once the material has cooled and nitrification has occurred, as may be the case during curing or storage.) In the past there has been perhaps some expectation that yard waste, in the absence of low C/N, might pose little risk to groundwater, but that belief may need reevaluation (e.g., Tonjes et al., 2018). Also, the presence of substances of concern in the raw materials (such as metals) may lead not only to their presence in the final compost (e.g., requiring the product testing in the previous section), but also in leachate. Other important factors for leachate generation include initial moisture content, wetting practices, and water holding capacity of the material. The extent to which leachate becomes run-off or percolates into the soil will depend on site factors such as impermeable surfaces and slope.

8.1 Leachate characterization

Krogmann and Woyczechowski, (2000) sampled leachate at two full-scale biogenic (source separated food and yard) waste facilities in Germany, as well as performing lab-scale experiments on various biogenic waste components individually. Although there was considerable variability, food waste composting leachate often had a higher BOD and COD than any of the other constituents tested (branches, grass, leaves, hedge cuttings, and miscellaneous yard waste), although grass clippings gave higher nitrogen concentrations. They also provided a table (reproduced here as Table 8-1) comparing their results to some from the literature, which further emphasized the high degree of variation encountered. Some of the leachate pollutant concentrations were <u>very</u> high – up to 45,000 mg/L BOD, 100,000 mg/L COD, 1600 mg/L total Kjeldahl nitrogen, and 150 mg/L total phosphorus.

Table 8-1. Table 7 from Krogmann and Woyczechowski (2000).

Table 7. Comparison of chemical and physical characteristics of liquid products from composting facilities from previous studies

		Leachate				Condensate			Runoff	
Composting method	Mixture This study	Ulén 1997 Covered windrows	Not covered windrows	Cole 1994 Not covered windrows	Loll 1994 Various	This study 85-L reactor	115-L reactor	Loll 1994 Various	This study Not covered windrows	Loll 1994 Various
Waste type‡	B	B	B	Y	B, Y	B, F	B,Y	B, Y	B	B, Y
pH		7.6	7.9	8.35–9.2	5.8–8.6	3.09–8.93	3.08–9.36	8.0–8.6	6.62–8.47	7.0–8.1
Conductivity	9.37–27.94	5.9	6.0	3.89–6.4	4.1–14.7	0.03–16.54	0.00–38.60	1.8–2.5	–	1.3–8.8
BOD_5	8–11, 571	–	–	–	10 000–45 000	< 1–2797	1–41 840	100–1000	< 2–513	100–1200
COD	2434–31 812	–	–	–	20 000–100 000	5–12, 208	3–77, 159	500–2000	56–1768	500–2500
TOC	–	920	610	–	5000–18 000	–	–	< 50–500	–	< 50–500
VFA	118–9535	–	–	–	–	–	–	–	–	–
NH_4^+-N	98–558	–	–	5.1–10.5*	50–800	< 0.1–3286	0.03–5960	< 5–100	2.0–46.0	15–300
NO_3^--N	–	–	–	3.6–5.8†	< 5–190	–	–	< 1	< 0.1–96.4	< 5–150
NO_2^--N	–	–	–	–	–	–			< 0.1–0.80	–
TKN	250–1602	–	–	–	–	< 0.1–3442	< 1–9482	–	–	–
Total N	–	240	420	–	–	–	–	–	–	–
Total P	–	28	16	–	50–150	–	–	< 1	–	< 1–50
K^+	–	620	1170	1629–2323	1075–7280	–	–	–	–	–
Ca^{2+}	–	340	280	386–462	–	–	–	–	–	–
Mg^{2+}	–	110	110	213–290	–	–	–	–	–	–
Na^+	–		430	640	–	–	–	–	–	–
Mn	–	–	–		1.5–3.5	–	–	–	–	–
Fe	–	–	–		16–52	–	–	–	–	–
S	–		60	60	–	–	–	–	–	–
Cl^-	1514–5254	780	1150	–	2 000–10 000	–	–	–	106–445	30–500
As	–	–	–	–	–	–	–	–	0.001–0.044	–
Cr	–	0.16	0.10	0.02–0.06	–	–	–	–	–	–
Ni	–	0.21	0.13	–	0.07–2.6	–	–	< 0.04	–	< 0.05–1
Cu	–	0.31	0.19	0.25–0.38	–	–	–	–	–	–
Co	–	–	–	–	0.01–0.2	–	–	< 0.05	–	< 0.05–0.2
Zn	–	0.79	0.30	–	1–8	–	–	0.2–1.6	0.011–2.4	< 1–2
Cd	–	0.01	– n.d.	< 0.1	0.01–0.2	–	–	< 0.02	< 0.001–0.172	< 0.05–0.2
Hg	–	–	–	–	–	–	–	< 0.0005	–	–
Pb	–	0.03	– n.d.	< 0.25	0.01–0.2	–	–	< 0.1	< 0.001–0.500	< 0.1–0.2

pH unitless, conductivity in mS cm^{-1}, other parameters in mg l^{-1}; * . NH_4; †. NO_3; ‡. B – biogenic waste; Y – yard waste; F – food waste; n.d. – not detected.

Elements of concern, such as lead, arsenic, cadmium, and mercury, are to be expected in the leachate only to the extent that they were present in the original materials (including bulking agent). Additionally, compost is often considered a good medium for immobilizing a variety of toxic constituents; however, the presence of high concentrations of colloidal and dissolved organic compounds may also mobilize some compost and soil constituents (Chatterjee et al., 2013.). Likewise, the reducing conditions induced by the presence of high concentrations of organic material in groundwater may solubilize some otherwise immobile soil constituents (USGS, undated). Harmful microorganisms may be present initially, or potentially grow if the conditions are suitable. Many toxic organic compounds, if present initially, are likely to be biodegraded during composting, but it is also possible for some degradation products to show toxicity.

Coker (2008a, b) also has discussed a number of the issues with stormwater runoff from composting facilities. In a recent report (Coker 2017) he applied some of his findings for a proposed facility in New Jersey. Coker (2008b) notes that the increasing requirements for water quality management, as well as odor control and air emissions, are important reasons to consider in-vessel composting and enclosure of operations within buildings.

8.2 Leachate quantity

Leachate often mixes with rainwater, which dilutes it. An important question is how much of the precipitation deposited on a site ends up as runoff, how much is temporarily retained by the composting material, and how much is permanently lost through evaporation (and/or percolation, for unpaved sites). Wilson et al. (2004) found that for nearly saturated composted cow manure in a laboratory physical model, with water applied as 4 relatively heavy simulated 20 minute "storms" (22, 30, 37, and 44 mm) over an 8 day period, very little leachate was generated immediately, but on average 68% of the applied water leached out over the 24 hours following each event. Likewise, at a full-scale facility composting sewage sludge with woodchips, in which the very wet (65% moisture content) material occupied 68% of the pad, again 68% of the rainfall over a one-month period was collected in the site's stormwater detention pond. Based on their results, the authors suggested that 68% was the maximum likely volumetric runoff coefficient for composting material, and that the material substantially delayed the release of runoff. Krogmann and Woyczechowski (2000) gave a more detailed analysis based on types of materials and facilities, and indicated leachate could be a little as 0% for covered materials; however, for open piles on paved surfaces, some runoff was unavoidable.

Kalaba et al. (2007) developed a stormwater runoff model for predicting the quantity of runoff for open windrows. They found a weighted runoff coefficient for the entire pad should be used, based on individual coefficients of 0.85 for the asphalt and 0.5 to 0.6 for the composting material. However, they noted the complexity of the hydrology resulting from the presence of the organic material, and the fact that its runoff coefficient might vary considerably based on the feedstock and the time it had been composting.

8.3 Effect of composting method

With respect to the effect of composting method on leachate generation, some limited information is available, and is summarized below.

Windrowing varies in terms of pile size, turning equipment, and turning frequency. No research on the effects of these factors on leachate quantity or quality was found for inclusion in this review. Based on field observations (U. Krogmann and P.F. Strom, independently), a dry outer layer often forms on windrows between turnings (unless it rains or snows heavily, in which case there may be a wet layer). This may act to absorb new rainfall in some cases, or it may act to shed some of the rainwater before it percolates through the pile. Where piles are inadequately moist initially and turned infrequently, a substantial dry inner mass has been observed. However, leachate has still been observed in all of these situations.

It seems generally agreed that aerated static piles are likely to generate less leachate, as they evaporate considerable amounts of water. Some of this water may form condensate, which may also need to be managed, as it can be highly contaminated, potentially even containing higher nitrogen concentrations than leachate (Table 8-1; Krogmann and Woyczechowski, 2000). Additionally, it seems likely that if decomposition occurs more rapidly, so that piles may be removed sooner, the amount of exposure to precipitation and hence the amount of leachate produced will be decreased. However, the need for a curing stage may reduce this potential advantage.

As discussed in Section 6 above, the use of synthetic covers (including plastic bags/sleeves such as EcoPOD® and EURO bagging technologies), semi-permeable sheeting (e.g., GORE-TEX®, and compost fleeces such as ComposTex®) and "biofilter" covers of finished compost will reduce leachate production. Placing a roof over the composting material may entirely eliminate leachate.

8.4 Site factors

Important site factors for leachate include proximity to surface water, depth to ground water, surface and soil permeability, and slope. Composting on an impervious surface facilitates collection of leachate for on-site treatment or discharge to a sanitary sewer, and may be necessary where compliance with groundwater quality standards is required.

It has been recommended (Strom and Finstein, 1994) that piles be oriented up and down, rather than across, slopes at the site. This helps minimize ponding of runoff in contact with the piles, which would otherwise increase the opportunity for additional leaching of contaminants.

8.5 Leachate control

Kennedy/Jenks Consulting (2007) provided a report for the Oregon Department of Environmental Quality that summarized 15 studies on leachate and runoff with the intent of providing guidance on the need for groundwater protection. They concluded that unless an area received low precipitation (does not apply in New Jersey), "the use of improved or impervious surfaces may be the most prudent method of protecting water resources…."

Coker (2008b) notes that "composting facilities must plan for control and management of storm water through a combination of both structural and nonstructural management techniques." He recommends "reduce, reuse, recycle." Reduction includes enclosing facilities, conducting activities under a roof, and segregating different runoff flows, so that lightly contaminated flows can be managed separately from more heavily contaminated ones (such as pile leachate). He also recommends stormwater pollution prevention plans (SWPPPs) with an objective to "implement and maintain best management practices (BMPs) that identify, reduce, eliminate, and/or prevent the discharge of stormwater pollutants" (WDEQ, 2004).

Wetting the composting material with collected stormwater is one method of reuse (Coker, 2008b). Of course, care must be taken to prevent this water from producing new leachate and runoff, but many composting piles dry during processing, and re-wetting may be needed. Recycling of the runoff for crop irrigation may be possible at some sites. Stormwater storage would be needed for both of these options.

A variety of best management practices (BMPs) are available for runoff treatment. CH2MHill (2004) ranked 27 stormwater BMPs for composting sites (for the Oregon Dept. of Environmental Quality) in 6 categories: space efficiency, odor control, cost, level of complexity, number of benchmark constituents potentially controlled, and usefulness for bacterial indicator, lead, and/or nitrate control. The resulting matrix is provided here in Table 8-2. The report recommends that "If technically and economically feasible, each site should employ some type of each of the BMP categories."

Table 8-2. BMP Ranking Matrix (Table 3-3 from CH2MHill, 2004).

BMP Number	BMP (By Type)	Space Efficiency	Odor Control	Cost[1]	Level of Complexity	Number of Benchmark Constituents Controlled[2]	E. Coli, Lead, and Nitrate Control (EC Pb NO3)
Oil and Grease							
1	Oil Water Separator	HIGH	N/A	LOW	LOW	7	Pb ONLY
Erosion, Sediment Control, and Debris Control							
2	Grading Facility Areas	N/A	YES	LOW	LOW	5	N/A
3	Appropriate Site Vegetation	MED	N/A	LOW	MED	5	YES
4	Graveling or Paving	N/A	YES	MED	LOW	5	N/A
5	Sediment Basins, or Traps	HIGH	YES	MED	LOW	5	YES
6	Bioswale or Grassy Swale	LOW	YES	LOW	MED	12	YES
7	Soil filter	MED	YES	LOW	MED	12	YES
8	Wetland	LOW	YES	LOW	MED	12	YES
9	Holding pond or detention facility	LOW	N/A	MED	MED	4	Pb NO3 ONLY
10	Sediment Control with Compost Filter Berms, Wattles, Bales, or Fences	MED	YES	LOW	HIGH	5	Pb ONLY
11	Sediment Control with Centrifugal Devices, Weirs, or Baffles	HIGH	YES	LOW	MED	5	Pb ONLY
12	Granular Filtration Tanks	HIGH	YES	LOW	HIGH	12	EC Pb ONLY
13	Soil and Plant Systems	MED	YES	LOW	HIGH	12	YES
14	Chemical Treatment	LOW	YES	HIGH	HIGH	12	YES
15	Coagulation and Sedimentation	LOW	N/A	HIGH	HIGH	12	YES
16	Aeration and Ozonation	LOW	YES	HIGH	MED	12	N/A
17	Underground Injection with Pretreatment	LOW	YES	HIGH	HIGH	9	N/A
Stormwater and Composte Leachate Diversion							
2	Grading Facility Areas	N/A	YES	LOW	LOW	5	N/A
3	Paving	N/A	YES	MED	LOW	5	N/A
18	Diversion with Containment Barriers, Curbing, Berms, Gutters	HIGH	YES	HIGH	LOW	5	N/A
19	Liner systems	N/A	N/A	MED	LOW	5	N/A
20	Collection and Reuse of Stormwater, Compost Leachate, or Washwater	LOW	N/A	MED	HIGH	12	N/A
21	Minimize Runoff by Practicing Specific Operating Procedures	N/A	YES	LOW	LOW	12	YES
Covering Activities							
22	Roof Structure	HIGH	YES	MED	LOW	12	YES
23	Membrane, Tarp, or Cover	HIGH	YES	MED	MED	12	YES
24	Indoor Operations	HIGH	YES	HIGH	HIGH	12	YES
Housekeeping							
25	Elimination of Standing Surface Water	N/A	YES	LOW	LOW	8	YES
26	Prompt Processing of Incoming Compost Feedstocks	N/A	YES	LOW	LOW	4	N/A
27	Shaping of Piles	HIGH	YES	LOW	LOW	6	YES

Notes:
1. See Table 3-2, Costs Associated with BMPs for details on cost. For ranking, cost is computed as capital cost/1000 + operating cost/100 and cost breakpoints are at 60 and 600.
2. See Table 3-1 for the list of specific constituents controlled and Table 5-2 for the list of benchmark constituents.

In some cases, it may be necessary to consider hauling collected leachate to off-site treatment facilities (Coker, 2008b), such as wastewater treatment plants. Discharge to a sanitary sewer may also be an option in some cases.

While many of the best management practices described are intended to prevent untreated or inadequately treated discharges to surface water, discharge to groundwater is also of potential concern. While controlled infiltration may be acceptable in some cases (e.g., as has been successfully practiced with properly designed and maintained septic systems in low density residential areas), current practice discourages this for composting operations. Food waste composting facilities that are small enough to potentially use this approach are likely also small enough that they can prevent or collect the leachate they generate.

Thus, surface and groundwater pollution at food waste composting sites should be avoided by employing the combination of best management practices selected as most appropriate for the particular material, operation, and site. These BMPs may include methods for the prevention of leachate/runoff production (e.g., by covering the site), collection of the flow, storage, treatment, reuse, and/or removal. Although a paved and/or lined operational area may increase total runoff produced, it is usually necessary to limit mud and other operational issues, and to minimize odors from ponded water that might otherwise accumulate in contact with the composting materials.

9. Air Emissions

9.1. Pollutants emitted to the air during composting operations

A wide range of pollutants may be emitted to the air during composting operations including particulate matter, volatile organic compounds (VOCs), odorous substances (including ammonia), greenhouse gases (particularly methane and nitrous oxide), and bioaerosols (discussed in Section 10). There are also air pollution emissions (especially particulate matter, VOCs and nitrogen oxides) from trucks delivering organic waste and transporting finished product, but those are not discussed here since that traffic would be evaluated separately as part of the County Solid Waste Management Plan.

Particulate matter emissions are likely to be generated by many activities including handling of feedstocks and amendments, turning of piles, movement of compost between processing areas, screening, bagging or loading for bulk transport of finished compost, wood grinding, and trucks travelling on unpaved roads. The most common particulate matter concern is classified as visible dust emissions.

VOC emissions are mostly generated as a by-product of the decomposition of the food waste and amendments. The individual VOCs are not of particular concern at the level at which they are likely to be emitted, but as a group they are important as precursors to tropospheric ozone. This group of pollutants is highly regulated in New Jersey because of the difficulty the State has had in meeting the National Ambient Air Quality Standard for Ozone.

The decomposition of food waste also generates odorous pollutants that normally are below thresholds set to protect public health, but can be above the level detectable by human noses. Thus odors are generally (but not always – see Section 10 below) considered a quality of life issue rather than a concern for human health. The level at which odors become a problem is subjective. Because of this, the emission rates and air concentrations of odorous substances often are not quantified. These emissions are usually addressed by implementation of best operating practices and then regulated in response to complaints from neighbors. It should be kept in mind that for composting sites in general, odors are the most common source of complaints and it is recommended that they be managed before they result in objections.

Ammonia may be among the odorous compounds emitted during composting. It has a lower health threshold than many of the other relevant odorous substances. The odor threshold for ammonia is reported to be 5 ppm (ATSDR, 2004). This is near the California 1-hour Reference Concentration of 4.6 ppm (CARB, 2019), but much lower than occupational standards, which are set at 25 ppm by Cal/OSHA, NIOSH and ACGIH (NJDOH 2016). Reports of ammonia exceeding occupational standards (intended for indoor work environments) in outdoor composting operations have not been encountered thus far.

Greenhouse gases are also a component of air emissions during composting, with methane being the most prominent (CARB, 2017). However, further consideration of this pollutant group was beyond the scope of this report.

9.2. Emission rates

Among the air pollutants resulting from composting operations, the emission rates of VOCs are of particular interest and are the focus of this subsection. Particulate matter is of concern if visible dust is observed. As mentioned above, problematic levels of odorous compounds are subjective, but will be obvious to neighbors if they are present at unacceptable concentrations. Odorous emission rates have been determined using olfactometry (Bidlingmaier and Müsken, 2007). Such values might be difficult to use for regulation and enforcement in New Jersey, but may be useful for dispersion modeling and sizing of buffer zones. Little information is available regarding emission rates for ammonia, though Pechan (2004) estimated a rate of 2.81 lb/ton of mixed waste as a good starting point.

Emission rates for VOCs will depend on feedstock composition, composting method, age of the pile, temperature, sunlight, oxygen content, humidity and pH. Although some work has been done in California (see emission factors in Table 9-1) it is difficult to identify a generally applicable emission factor. The two largest air districts in California (South Coast and San Joaquin Valley) have adopted emissions factors for composting operations that average around five pounds of VOC per ton of feedstock (CARB, 2018).

Table 9-1. Emission Factors for VOCs

VOC Emission Factor	Activity	Reference
5.71 lb/ wet ton	Windrows	SJVAPCD (2010)
1.3-2.6 lb/ wet ton of feedstock	Food waste during active composting period	California Integrated Waste Management Board (2007)
3.12 lb/ton	50:50 Biosolids to Green Waste ratio	Pechan (2004)
1.063 lb/wet ton /day	Stockpile for either Green Waste or Food Waste	SJVAPCD (2010)

9.3. Control technologies and best management practices (BMPs) to reduce emissions

9.3.1. Volatile organic compounds

VOCs will be generated regardless of the method that is chosen for composting, so preventing them from entering the air is the principal control method. California researchers have found that the most effective method for reducing emissions from compost piles is a combination of aeration, covering with a breathable fabric or finished compost, and maintaining proper moisture content. Forcing air through the piles, using an aeration system with a blower, maintains aerobic conditions within the piles. Compost caps have also been proven to be especially effective. California Integrated Waste Management Board (2007) has found that a compost cap composed of finished compost placed over the ridgeline of a well-managed windrow reduced VOC emissions by about 75% over the first two weeks of composting.

9.3.2. Particulate matter

Dusty operations such as handling of feedstocks and amendments, movement of compost between processing areas, screening and bagging of finished compost, wood grinding, and trucks travelling on unpaved roads may all be sources of particulate matter emissions at composting facilities. Dust generation can be minimized by maintaining optimal moisture content, including misting of dry materials. Paved roadways and working pads will also reduce dust generation by truck traffic (Environment Canada, 2013).

9.3.3. Odors

Odorous substances can be produced at every stage of the composting process, so a broad array of strategies is needed to control odors. "New Jersey's Manual on Composting Leaves and Management of other Yard Trimmings" (Strom and Finstein, 1994) provides guidance, noting that "The major problem encountered - even at leaf only composing sites - is odor." It outlines odor problems as developing in 4 stages, in which odorous compounds must:

1) be present initially or produced during processing;

2) be released from the pile (meaning they are in a volatile form);

3) travel off-site; and

4) be detected by a sensitive receptor.

While odor problems can be prevented by disrupting any one of the stages, it is generally agreed that it is most desirable to prevent problems at stage 1. This is normally best done by avoiding prolonged and/or extensive anaerobic conditions and by promoting the rapid degradation (through providing beneficial composting conditions for factors such as temperature, oxygen, and moisture content) of the compounds causing the odors, or of the putrescible compounds that breakdown to release them (Finstein et al., 1987c). In the absence of sufficient oxygen, volatile organic acids (which have vinegary, cheesy, goat-y, and sour odors), alcohols and esters (fruity, floral, alcohol-like), and amines and sulfur compounds (barnyard, fishy, rotten) can be produced. However, it should be noted that with low C/N wastes (high nitrogen content), ammonia odors may be released even under aerobic conditions.

Once odorous compounds are present, their escape (stage 2) can sometimes be prevented by minimizing pile disturbance; absorption, adsorption, and/or biodegradation within a biofilter-like cover; and/or pH adjustment. Some of the odorous compounds (e.g., acetic acid, hydrogen sulfide) are acidic, and will dissociate to an ionic form (and thus be rendered non-volatile) under neutral to alkaline conditions. This means that limestone addition is sometimes beneficial. However, some odorous compounds (ammonia, amines) are bases; their release can be minimized under more acidic conditions, but may be increased if lime is added.

Once odors are released, an effort can be made to minimize their off-site effect by trying to time odor-releasing operations (e.g., turning) to coincide with favorable wind conditions. A windsock or weathervane is useful for determining when wind direction is away from nearby receptors. Additionally, lower wind speeds are associated with worse odors, as they provide less dilution as air passes over the odor-releasing material, and also with less turbulence leading to less vertical mixing. Temperature inversions trap odors near the ground, and thus may represent another important factor to consider.

Morrison Hershfield (2017) includes a comprehensive list of best practices for odor management in their report to Metro Vancouver. The California Code of Regulations (17863.4) provides a regulatory framework for requiring best practices in an odor management plan. In general, well-constructed, properly aerated piles will produce fewer odors, but some type of cover (similar to those chosen for VOC control) will also be necessary. During handling of raw materials, odors can be minimized by moving food waste into composting piles on the same day that they are received. Odors must also be addressed during post-processing of compost and leachate management. Table 9-2 includes a sampling of best practices, including management plans for identifying and addressing odor episodes, found in a variety of sources, but especially well described by Morrison Hershfield (2017). A well-managed composting facility would use almost every one of these BMPs.

Some have advocated the use of anti-odorant sprays to control odor episodes. However, the DEP Division of Air Quality (DAQ) does not allow the use of deodorizing agents as they only mask the smell, which does not solve the problem if the underlying chemical causes health issues. DAQ does allow the use of “neutralizing” agents as they chemically/physically react with the substances that originally caused the odor. However, before use a neutralizing agent must be reviewed by DAQ to confirm that there will be no health risk to receptors beyond the fence line of the facility.

Table 9-2. Best Management Practices (BMPs) for Odor Control*

OPERATION	BMP for Odor Control
Waste Material Storage & Transport	Cover collection/delivery vehicles should be covered and equipped with a leachate containment system.
	Make deliveries to an indoor space equipped with air pollution control equipment (e.g., a biofilter).
	Place waste into composting piles on the day they are received. If incoming feedstock is very odorous or wet, collection frequencies might need to be increased and the feedstock needs to be processed more quickly.
	Develop good housekeeping practices that include removal of spilled feedstock from facility roads and other areas daily, and cleaning of delivery vehicle wheels and loading area before leaving the site.
Pre-processing (e.g., screening, grinding, mixing)	Ensure that sufficient amounts of bulking agent are available to avoid odorous leachate if incoming feedstock is very wet.
	Cover odorous materials left over from screening.
Composting Process	Cover aerated static piles with a membrane or layer of finished compost to contain odors.
	Carefully control aeration rates, temperature, oxygen, and moisture.
	Limit material movements to times when weather conditions are unlikely to carry odorous substances to off-site receptors.
	Ensure sufficient compost stability before compost is moved to post-processing.
Post-Processing (Screening)	Limit screening to times when weather conditions are unlikely to carry odorous substances and dust to off-site receptors.
Leachate Management	Aerate water retention basins to avoid odors. Aeration should be a part of the stormwater management design.
	Avoid ponding of water in contact with organic material.
General Management Tools	Provide training for staff regarding procedures and maintenance that will minimize generation of odors, and regarding plans to address odor incidents expeditiously.
	Plan to regularly note any odorous conditions and immediately address them.
	Plan to respond to odor complaints.
	Lay out procedures for proper maintenance of yard waste and other amendments stockpiles.
	Lay out procedures for proper maintenance of materials left over from screening.
	Ensure that the facility capacity is not exceeded.
	Use on-site meteorological station to measure wind speed and direction is helpful if sensitive receptors are nearby and in a particular direction.

* From several sources, but most are especially well described in Morrison Hershfield (2017), California Code of Regulations (2019), and Cal Recycle (2005).

9.4 Air permitting requirements

The Air Pollution Control Regulations set out at N.J.A.C. 7:27 identify the type of operations that need an Air Permit in the State of New Jersey. In N.J.A.C. 7:27.8.3(a) the Permit Regulation states:

> No person may construct, reconstruct, install, or modify a significant source or control apparatus serving the significant source without first obtaining a preconstruction permit under this subchapter.

N.J.A.C.7:27-8.2 lays out all the different types of operations that may be considered significant. The activities most likely to be found at a composting facility are contained in subsections 8.2(c)10, 11, 16, 17 and 19:

7:27-8.2 Applicability

(c) Any equipment or source operation that may emit one or more air contaminants, except carbon dioxide (CO_2), directly or indirectly into the outdoor air and belongs to one of the categories listed below, is a significant source (and therefore requires a preconstruction permit and an operating certificate), unless it is exempted from being a significant source pursuant to (d) or (e) below:

10. Tanks, reservoirs, containers and bins which have a capacity in excess of 2,000 cubic feet [74 yd^3] and which are used for the storage of solid particles;

11. Stationary material handling equipment using pneumatic, bucket or belt conveying systems from which emissions occur;

16. Equipment that is used for treating waste soils or sludges, including municipal solid wastes, industrial solid wastes, or recycled materials, if the influent to the equipment has a solids content of two percent by weight or greater. Typical operations performed by this type of equipment include, but are not limited to, soil cleaning, composting, pelletizing, grit classifying, drying, and transfer station operations. However an area used as a temporary storage area, such as a concrete pad or a roll-off container, shall not be considered to be equipment used for treating waste soils or sludges, provided that the area is not also used for treatment;

17. Equipment used for the purpose of venting a closed or operating dump, sanitary landfill, hazardous waste landfill, or other solid waste facility, directly or indirectly into the outdoor atmosphere including, but not limited to, any transfer station, recycling facility, or municipal solid waste composting facility;

19. Equipment in which the combined weight of all raw materials used exceeds 50 pounds in any one hour, provided:

i. Such equipment shall not include equipment which is the same type as is included within a category described in (c)1, 2, 4, 5, 6, 7, 8, 9, 10, 12, 15 or 18 above; or in (c)20 below, but which is excluded from the category because it does not meet an applicability threshold set forth in the description of the category. That is, the equipment has a lower capacity, weight of materials processed, vapor pressure, or consumption of BTUs, or otherwise falls outside a parameter that is included in the description of the category;

Regardless of whether a facility needs an Air Permit, it will still be subject to the General Provisions of the Air Pollution Control Rules as stated in 7:27-5.2

(a) Notwithstanding compliance with other subchapters of this chapter, no person shall cause, suffer, allow or permit to be emitted into the outdoor atmosphere substances in quantities which shall result in air pollution as defined herein.

Under this requirement, off-site odors and visible emissions are not permitted. If offsite odors or dust do occur, the DAQ may require an odor or dust control plan even if no air permit is required for any other reason. A dust control plan should address procedures that would minimize dust from handling of feedstocks and amendments, movement of compost between processing areas, screening and bagging of finished compost, wood grinding, and trucks travelling on unpaved roads. An odor control plan should address means to place organic wastes within piles on the same day that they are received; leachate management techniques; and strategies for identifying odor incidents and responding to complaints.

If an operation is very large (emitting more than 25 tons/year of VOC), it also would be subject to Operating Permit requirements in N.J.A.C. 7:27-22. Using the California VOC emission factor of 5 pounds of VOC per ton of feedstock, it would appear that such a facility would have to process about 20,000 cubic yards of compostable material per year to trigger Operating Permit requirements.

10. Potential Human Health Effects

Concern for health effects from composting is not new, although few serious outcomes are documented. There is a substantial dearth of reports in the literature of serious health outcomes in workers or nearby community members. Nevertheless, the risks are real and deserve continued attention using more sophisticated research techniques. Foci of concern generally revolve around risks for serious health outcomes from established pathogens or toxic agents. Although these previously documented outcomes have been associated with different settings or with susceptible populations, the specific agents (mostly microorganisms, with some VOCs) are known to be constituents of, or amplified by, composting processes (e.g., Finstein et al., 1987c). This section will first consider potentially adverse exposures that can be present in composting operations and then address current evidence for associated health outcomes in both workers and communities. The recent literature has two excellent reviews and one meta-analysis on this topic (Domingo and Nadal, 2009; Robertson et al., 2019; Pearson et al., 2015). Health concerns associated with the product (compost) are discussed above under testing requirements. No literature specific to food waste was identified.

10.1. Exposures

Exposures can be categorized as microbiological or toxic, the latter including metals, polycyclic aromatics, and VOC's. Microbiological exposures are of greatest concern because they can induce acute, life-threatening illness. This is based on two specific disease processes, allergy or infection, and is not as strictly dose related as with toxicant effects. Metals and other inorganic toxicants generally require high and/or prolonged concentrations or doses to induce clinically recognizable toxic effects, e.g., metal poisoning. This contrasts with fungi and other microbes whose effects can be multiplied in the host by allergic or infectious processes. While risks are higher with greater concentrations or doses of bioaerosols, they are not eliminated by moderate or low exposures, which can induce disease in those with appropriate susceptibility such as atopy or immune deficiency. Additionally, some fungal species, such as several in the genus *Aspergillus*, are normally present in substantial concentrations in composting materials and can contribute meaningfully to the composting process.

10.2. Health outcomes

Aspergillus, particularly *A. fumigatus*, is a ubiquitous fungus that grows best under warm, aerobic conditions. An early review, after it was recognized as sometimes abundant at composting facilities, was provided by Marsh et al. (1979). It occurs in most soils and can also be found in homes, offices, and the ambient air. It is well-known to produce a number of characteristic, relatively uncommon, but serious and even fatal outcomes. Most lethal is invasive aspergillosis, a systemic and often difficult to treat infection. Increased concentrations of *Aspergillus* spores apparently contribute to increased risk in the immunosuppressed. This infection is largely confined to those with impaired immunity due either to inherited immunodeficiency, cancer chemotherapy, pharmacologic immunosuppression with steroids or biologics, or inter-current debilitating disease including HIV/AIDS, alcoholism and diabetes. This is of growing concern due to the increasing prevalence of such susceptible individuals in our population. Also, people taking antibiotics may depress their normal bacterial community, increasing the risk of infection by opportunistic fungal pathogens (Clark et al., 1984). Immunocompetent individuals are resistant to *Aspergillus* infection and have negligible concerns in terms of *Aspergillus* infection.

Other serious but less lethal conditions caused by *Aspergillus* species (and other microorganisms such as some thermophilic actinomycetes) include hypersensitivity pneumonitis (extrinsic allergic alveolitis), a type of immune-mediated acute pneumonia, which is mediated by a characteristic immunological reaction to various inhaled organic antigens. Cases are difficult to diagnose and rare. Farmer's Lung is the classic example of this, due to inhalation of overgrowth of actinomycetes in moldy grains. Similarly, allergic bronchopulmonary aspergillosis, which can also affect the sinuses, is an atopic allergic condition only seen in asthmatics.

A more concentration-dependent outcome is irritation of mucous membranes and the upper respiratory tract by bioaerosols containing bacteria, fungi, mycotoxins, and other microbial constituents as well as VOCs. Not only are bioaerosols potential irritants, but they also convey, particularly in workers, increased risks of atopic upper respiratory sensitization clinically manifest as diagnosable conditions such as pharyngitis, rhinitis, and conjunctivitis, along with lower respiratory conditions such as bronchitis and asthma (Robertson et al., 2019).

Another important biological agent is *Legionella* spp. (the cause of Legionnaire's disease), particularly *L. pneumophila*. Exposure to this organism, which is common in soil and grows in water tanks, whirlpools and similar environments is via inhalation and produces a potentially lethal pneumonia infection. Large outbreaks of over 100 cases from contaminated water sources are documented. While *Legionella* species are found in compost, no composting-associated cases are described in the literature.

10.3. Occupational health

A number of studies of composting workers have been reported as case series (see Domingo and Nadal, 2009; Robertson et al., 2019). Increased rates of mucous membrane symptoms and lower respiratory system symptoms such as bronchitis are well-documented but increases in other lung diagnoses or permanent impairment in pulmonary function has not been described. One new worker at a vegetative waste composting facility in Belgium, who regularly hand-turned composting piles, developed an "extremely rare" case of hypersensitivity pneumonitis, probably complicated by invasive bronchopulmonary aspergillosis; he changed jobs and fully recovered (Vincken and Roels, 1984). Likewise, one worker at a large sewage sludge composting facility that utilized woodchips as a bulking agent developed an *Aspergillus niger* ear infection (Clark et al., 1984). In this overall study Clark et al. (1984) examined four large sewage sludge composting facilities, including one in Camden, NJ, and compared workers with high exposure to composting dust to those with lesser exposure and controls. The group with higher exposure was found to score higher on tests of exposure to *A. fumigatus* and some other measures, but generally not to have higher incidence of disease. While respiratory protection and water suppression of dust are recommended, this seems largely to be based more on precautionary common sense and comfort than on a documented need for avoidance of specific pathogens.

10.4. Community health

One community environmental study from the UK, using an ecological design, examined 34,963 hospital admissions for respiratory conditions within 250-2500 meters of a large open-air composting facility (Douglas et al., 2016). There were no significant associations between admissions and distance of home addresses from composting facilities. Moreover, sensitivity analyses demonstrated no significant associations with subgroups of respiratory infections, asthma or COPD. This study represents an ambitious approach, likely limited by its focus on hospitalized (rather than outpatient) infections, as well as potential exposure misclassification, diluting its power, and an inability to focus on susceptible immunocompromised individuals. Another similar ecological study from the same group, using modeled *Aspergillus fumigatus* concentrations (instead of distance from the plant as a proxy) for 76 composting facilities was also null (Roca-Barcelo et al., 2019). These studies deserve replication with more robust study designs, particularly a consideration of non-hospitalized conditions such as allergic respiratory disease.

A case of allergic bronchopulmonary aspergillosis was documented in a young man living within 250 feet of a large leaf composting facility in suburban New Jersey (Kramer et al., 1989). Wind direction was reported to be from the site towards the home 52% of the time.

A number of European countries have established health relevant levels for bacteria and/or fungi at composting facilities. The U.K. Environment Agency has established acceptable levels above background of 1000 Colony Forming Units (CFU) per m^3 for total bacteria, 300 cfu/$m^3$for gram negative bacteria (source of endotoxin) and 500 CFU for A. *fumigatus* (Pearson et al., 2015). Monitoring for gram negative bacteria is no longer required (U.K. Environment Agency, 2018a, b). Importantly, while employers are provided with guidance on how to protect workers by assessing risk and controlling exposures to as low as reasonably possible, there are no quantitative exposure limits for workers in the U.K. Employing the precautionary principle, the U.K. Environment Agency also has a guidance specifying that composting facilities with sensitive receptors (workplaces and homes) within 250 m of the fence line must complete a risk assessment for that site and monitor bioaerosols (Pearson et al., 2015). Germany has proposed a Technical Control Value of 50,000 CFU per m^3 for mesophilic (growing maximally at ambient temperatures) fungi (Federal Institute for Occupational Safety and Health, 2013 and 2019). The Netherlands has a proposed an occupational standard of 90 endotoxin units (EU) per m^3 over 8 hours (DECOS, 2010). Poland has a limit of 100,000 CFU per m^3 for mesophilic bacteria, 50,000 CFU per m^3 for fungi, and 2,000 EU per m^3 for endotoxin (Gutarowska et al., 2015). Overall one can see that although many agencies are in the same neighborhood with respect to setting buffer boundaries and standards around plants, much work needs to be done.

10.5. Odors

Lastly, the impact of odors associated with composting, particularly when done in the open may be the greatest source and trigger of community concerns (Herr et al., 2003). Although not lethal, odors can substantially diminish quality of life and are also associated with stress, elevated blood pressure, and asthma attacks. It is anticipated that expanding the feed stock to food waste, including meat and dairy, will exacerbate this problem.

10.6. Conclusions

Serious health effects from composting have not yet been shown to be common or even implicated as an important threat to public health. Nevertheless, it is not a well-studied area and the threat to people who have any degree of immunosuppression needs further exploration.

11. Buffer Zones

Buffer zones may be beneficial in minimizing off-site environmental and public health impacts, and are sometimes implemented for surface water, groundwater, bioaerosols, odor, and noise, among other factors. Only bioaerosols and odor will be considered here.

Austria, a country with a long composting history and many small open facilities, has developed best practices for composting facilities (Amlinger et al., 2009). According to these best practices, each site is unique and odor dispersion modeling is considered the state of the art for siting of composting facilities. Although they are inflexible, buffer zones are simple to implement, so practice also includes a list of buffer zone sizes addressing odor nuisances from composting facilities. These zones range between 300 and 1000 m (980 - 3280 ft), and are differentiated by feedstock, throughput, level of enclosure, and type of receptor. In comparison to yard waste composting operations, all facilities processing bio-waste (source-separated food and yard waste) require a detailed odor assessment for a proposed composting site. The assessment outlined in the guidelines includes odor dispersion modeling. If an already operating facility is assessed an on-site investigation can replace the odor dispersion modeling. On a case-by-case basis the detailed odor assessment can be omitted for facilities processing less than 1000 metric tons/yr.

The Austrian guidelines also mention cases where temperature inversions occurred and odor complaints beyond 1000 m were reported. Thus daily operations may be adjusted based on meteorological conditions (Lung, 2003).

With regard to bioaerosols, Amlinger et al. (2009) note that because assessing human health risk is problematic (due to the lack of a clear dose-response relationship), acceptable exposure levels cannot be set. Instead they focus on reducing bioaerosol formation through best management practices (BMPs). In open composting, this includes wetting material before and/or during turning or moving piles, covering piles, and timing operations based on meteorological conditions. However, they also note that, depending on topography and wind, bioaerosol concentrations normally have dropped to background levels within 150-200 meters downwind. Note that such a buffer zone is much smaller than the one recommended for odor (300-1000 m), and is also much less than those discussed below.

Millner et al. (1980) developed emission estimates and dispersion models for *Aspergillus fumigatus* and other bioaerosols released from biosolids composting facilities during turning with a front-end loader. Under some of their better case scenarios (unstable atmospheric conditions), bioaerosol levels returned to background within 500-600 m, but the emission rates in their tests may have been higher than would be the case with current BMPs in place. They also noted that counts often returned to background levels shortly (minutes) after turning of piles and other disturbances of the material ceased.

Douglas et al. (2017) used dispersion modeling to predict *A. fumigatus* exposure from composting facilities. They concluded that such an approach may be useful, although additional work was needed. It also appears from their work that concentrations could still remain relatively high at 600 m. This would reinforce the suggestion of Amlinger et al. (2009) from above to place an emphasis on BMPs to reduce bioaerosol emissions.

Many government entities have recommended buffer zones around facilities or quantitative exposure regulations or guidelines aimed at preventing adverse health outcomes. One early study demonstrated elevated viable *Aspergillus* and thermophilic actinomycetes detectable at least 500 m downwind of a composting facility (Recer et al., 1991). For New Jersey leaf composting sites, Zwerling and Strom (1992) found *A. fumigatus* counts, during site activities such as turning, to decrease with distance from the site, but to still be elevated above typical background levels at distances of 1250 ft (381 m), the longest distance measured at any site. Counts did decrease quickly after activity ceased.

Williams et al. (2019) used dispersion modeling to predict *A. fumigatus* exposures from British outdoor composting plants. Their projections are meant to be qualitative, and seem to overestimate airborne concentrations. However, the results suggest that a buffer of about 670 m would be needed to reach the current regulatory limit of 500 cfu/m^3 above background, and that the current buffer of 250 m reduces the count only to 1400 cfu/m^3.

12. Size of Composting Facilities

Small quantities of material, such as are typical in residential backyard composting, are unlikely to represent a leachate problem as long as they are not located directly on a stream bank. However, as the amount of material increases, the potential biochemical and chemical oxygen demands (BOD and COD), nutrient (nitrogen and phosphorus), and other contaminant loads (mass per time) increase, representing possible surface water and groundwater risks. There is no obvious threshold at which these impacts start to occur. Likewise, odors from very small piles are unlikely to pose a problem unless they are located directly next to a sensitive receptor, such as a residence.

Idaho (State of Idaho DEQ, 2013), as an example, has defined 4 levels of management for composting facilities, including those that accept food waste, based on volume and composition. "Below Regulatory Concern" applies to facilities handling up to 300 cubic yards on site at one time, and that accept food waste without meats or animal fats. Tier I facilities may accept the same wastes up to 600 cubic yards. Tier II composting facilities can accept larger volumes of a variety of compostable materials, but the waste must not pose a substantial threat to public health or the environment, while Tier III facilities handle wastes or volumes that do pose such risks. However, no references or other documentation is provided in this document indicating the basis for the particular size or materials limitations; likely it was based on the professional judgment of one or more of the individuals advising the developers of the guidelines or the developers themselves.

Note that 300 cubic yards would be about 50 yards of pile length with a cross-sectional area of 6 square yards (about 6 feet high by 12 feet wide, with a semicircular shape). It is not clear that operations of that size necessarily would be "below regulatory concern" in New Jersey, depending upon the material handled and where it was located.

Other states have likewise recognized a need to streamline requirements for small composting facilities handling less problematic wastes if they wish to encourage composting. According to a summary prepared for Illinois (IFSC 2015), Massachusetts reduced permitting requirements for composting facilities that handle less than 20 cubic yards/day (< 1 compactor truck) of food waste (about 5000 cubic yards/year for a 5 day work week), New York set the limit at 1000 cubic yards/year (currently different; see below), and North Carolina sets the cut-off at 1000 cubic yards of food waste per quarter (4000 cubic yards/year). In Maine, reduced requirements apply for wastes with C/N between 15/1 and 25/1 if the volume is less than 400 cubic yards/month (4800 cubic yards/year). The intent in all cases appears to be minimization of the regulatory burden while still ensuring protection of public health and the environment. The wide range of limits may reflect local conditions and sensibilities, differences in the types of materials managed, or a lack of objective criteria or data upon which to set the levels. Also, of course, the relationship between the amount on site at one time (as used in Idaho) and the amount received per time period (the 4 other states mentioned) will depend on how long material stays on site.

Current New York State regulations (NYSDEC, 2019a, c) define 3 levels of regulatory oversight based on capacity that apply for composting facilities that accept food waste:

1) "exempt" applies if ≤ 1 yd^3/day (also applies to home composting);

2) “registration” applies for ≤5,000 yd^3/yr;

3) “permit” applies for > 5000 yd^3/yr.

Exempt facilities must be “operated in a manner that does not produce vectors, dust or odors that unreasonably impact neighbors of the facility, as determined by the department, and when no waste remains on-site for more than 36 months”. Registration involves notification and operating requirements.

Washington State updated their 2003 composting rules in 2013 in order to grant exemptions for some types of green waste composting under certain conditions (Platt, 2016). The rules (WAC, 2018a) set out five conditional exemptions, but only the first two, for “All organic feedstocks”, potentially apply to food wastes:

(1) ≤ 25 yd^3 of material on-site at any time

(2) ≤ 250 yd^3 of material on-site at any time, and ≤ 1000 yd^3 of material per calendar year

For exemption (1), there are no notification, reporting, or testing requirements. For (2), the state and the local health department must be notified, and if there is distribution of compost off-site, several operational, testing (yearly), and reporting (yearly) requirements must be met. The testing requirements are the same as those included above in Table 7-2. Importantly, regardless of any exemptions, Washington rules also include a performance standard (WAC, 2018b), which specifies that the owner/operator must design, construct, and operate the facility “in a manner that does not pose a threat to human health or the environment.” The conditional exemption is also based on other requirements, including operation to “control nuisance odors to prevent migration beyond property boundaries” and “prevent attraction of flies, rodents, and other vectors.”

There does not seem to be specific published empirical research that can be used to define the size of a food waste composting operation that is “below regulatory concern,” for which no permit requirements are ever needed. However, based on the observations of researchers and practitioners, it does seem likely that, if they do not handle especially problematic materials, many “micro-sites”, such as those that might be incorporated in a small community urban garden, could be operated with only minimal requirements. These might include provisions to prevent leachate from entering surface water or storm sewers, minimize dust (and bioaerosol) production (e.g., by lightly wetting pile surfaces before and/or during turning), and by operating in such a way as to minimize odor release and avoid odor complaints. One caveat could be that the pile will be removed if odors cannot be quickly controlled or if other problems develop.

13. References

Amlinger, F., Pollak, M., and Favoino, E. (2004). Heavy metals and organic compounds from wastes used as organic fertilisers. ENV.A.2./ETU/2001/0024. Final report for Directorate-General for the Environment of the European Commission. https://ec.europa.eu/environment/waste/compost/pdf/hm_finalreport.pdf, accessed 3/11/20.

Amlinger, F., Peyr, S., Hildebrandt, U., Müsken, J., and Cuhls, C. (2005). Stand der Technik der Kompostierung, Grundlagenstudie (State of the Technology of Composting, Baseline Review: in German). Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft, Vienna, Austria. (see below).

Amlinger, F., Hildebrandt, U., Müsken, J., and Cuhls, C. (2009). The State of the Art of Composting – A Guide to Good Practice, Austrian Ministry for Agriculture and Forestry, Environment and Water Management, Vienna, Austria. https://www.bmnt.gv.at/umwelt/abfall-ressourcen/behandlung-verwertung/behandlung-biotechnisch/richtlinie_sdt.html, accessed 1/31/20 (includes download links for both original German and English versions, as well as Amlinger et al. 2005 technical report in German immediately above.)

Anon. (2017). Sustainable Generation and GORE® Cover Membrane Covered Positive ASP Composting Technology. W. L. Gore & Associates, Sustainable Generation LLC. Available at http://calgreeneng.com/wp-content/uploads/2018/04/Gore-Cover-Clean-Compost-Technology-March-2017.pdf.

ATSDR (2004). Public Health Statement for Ammonia. Agency for Toxic Substances and Disease Registry. https://www.atsdr.cdc.gov/phs/phs.asp?id=9&tid=2, accessed 3/18/20.

Avidov, R., I. Saadi, A. Krasnovsky, S. Medina, M. Raviv, Y. Chen and Y. Laor. (2018). Using polyethylene sleeves with forced aeration for composting olive mill wastewater pre-absorbed by vegetative waste. *Waste Management*, 78, 969–979.

Berge, A. C. B., Glanville, T. D., Millner, P. D. and Klingborg, D. J. (2009). Methods and microbial risks associated with composting of animal carcasses in the United States. *Journal of the American Veterinary Medical Association*, *234*(1), 47-56.

Bernal, M. P., Sommer, S. G., Chadwick, D., Qing, C., Guoxue, L. and Michel Jr, F. C. (2017). Current approaches and future trends in compost quality criteria for agronomic, environmental, and human health benefits. In *Advances in agronomy* (Vol. 144, pp. 143-233). Academic Press.

BGK (2010). Hygiene Baumuster-Prüfsystem (HBPS): Kompostierungsanlagen, Vergärungsanlagen; 4. ergänzte und überarbeitete Auflage (Hygiene Type Test System (HBPS): Composting plants, Fermentation plants; 4. Supplemented and revised edition.

https://www.kompost.de/fileadmin/user_upload/Dateien/Guetesicherung/Dokumente_Kompost/HBPS.pdf (accessed 4/21/20).

BGK (2017). Gütesicherung Kompost (Compost Quality Assurance). https://www.kompost.de/guetesicherung/guetesicherung-kompost/ (accessed 7/10/19)

Bidlingmaier, W. (1983). Das Wesen der Kompostierung von Siedlungsabfällen (Basics of MSW composting: in German). In: Hösel, G., Bilitewski, B., Schenkel, W. and Schnurer, H. (eds.) *Müll-Handbuch*, vol. 5 KZ 5305. Erich Schmidt Verlag, Berlin, Germany.

Bidlingmaier, W., and Müsken, J. (2007). Odor emissions from composting plants. In Waste Management Series (Vol. 8, pp. 215-324). Elsevier.

BioCycle (2014). State orders closure of Peninsula compost facility. https://www.biocycle.net/2014/10/23/state-orders-closure-of-peninsula-compost-facility/ (accessed 7/10/19).

Boldrin, A., Christensen, T.H., Körner, I., and Krogmann, U. (2011). Composting: mass balances and quality. In Solid Waste Management and Technology, Volume 2, T.H. Christensen (Ed.), John Wiley and Sons, Ltd., Chichester, U.K, pp. 569-582.

Brinton, W. F. (2000). Compost quality standards and guidelines. Final Report by Woods End Research Laboratories for the New York State Association of Recyclers.

Brinton Jr, W. F., Storms, P., and Blewett, T. C. (2009). Occurrence and levels of fecal indicators and pathogenic bacteria in market-ready recycled organic matter composts. *Journal of Food Protection*, 72(2), 332-339.

Burge, W.D., Colacicco, D., and Cramer, W.N. (1981). Criteria for Achieving Pathogen Reduction during Composting. J. Water Pollution Control Fed. 53: 1683-1690.

California Code of Regulations (2019). 14 CCR Section 17863.4 Odor impact minimization plan, https://govt.westlaw.com/calregs/Document/I31D188B73FF04F7599512C43DAE2E0B1?viewType=FullText&originationContext=documenttoc&transitionType=CategoryPageItem&contextData=(sc.Default), accessed 1/10/20.

California Compost Quality Council (CCQC). (2001). Compost maturity index. California Compost Quality Council, Nevada City, CA.

California Integrated Waste Management Board (2007). Emissions testing of volatile organic compounds from greenwaste compost at the Modesto Compost Facility in the San Joaquin Valley. Publication No. 442-2007-0009, https://www2.calrecycle.ca.gov/Publications/Details/1263, accessed 1/10/20.

Cal Recycle (2005). Odor impact minimization plan. https://www.calrecycle.ca.gov/swfacilities/compostables/odor/oimp, accessed 3/18/20.

CARB (California Air Resources Board) (2017). Final draft method for estimating greenhouse gas emission reductions from diversion of organic waste from landfills to compost facilities, https://www.arb.ca.gov/cc/waste/cerffinal.pdf, accessed 1/10/20.

CARB (2018). Composting in California: addressing air quality permitting and regulatory issues for expanding infrastructure, http://californiacompostcoalition.org/wp-content/uploads/2018/11/FINALC1-1.pdf, accessed 1/10/20.

CARB (2019). Consolidated Table of OEHHA / CARB approved risk assessment health values. https://ww2.arb.ca.gov/resources/documents/consolidated-table-oehha-carb-approved-risk-assessment-health-values, accessed 3/18/20.

Cerda, A., Artola, A., Font, X., Barrena, R., Gea, T. and Sánchez, A. (2018). Composting of food wastes: status and challenges. *Bioresource Technology*, *248*, 57-67.

Chatterjee, N., Flury, M., Hinman, C., and Cogger, C.G. (2013). Chemical and physical characteristics of compost leachates: A review. A report prepared for the Washington State Department of Transportation, https://www.wsdot.wa.gov/research/reports/fullreports/819.1.pdf, accessed 1/10/20.

CH2MHill. (2004). Commercial composting water quality permit development. Oregon Department of Environmental Quality, Contract No. 044-04.

Chiumenti, A., Chiumenti, R., Diaz, L.F., Savage, G.F., Eggerth, L.L. and Goldstein, N. (2005). *Modern composting technologies*. J.G. Press, Emmaus, PA.

Clark, C.S., Bjornson, H.S., Schwartz-Fulton J., Holland, J.W., and Gartside, P.S. (1984). Biological health risks associated with the composting of wastewater treatment plant sludge. J. Water Pollution Control Fed. 56:1269-1276.

Coker, C. (2008a). Managing storm water. *BioCycle*, 49(2), 28-34.

Coker, C. (2008b). Storm water treatment. *BioCycle*, 49(4), 29-36.

Coker, C. (2016). Controlling composting odors. *BioCycle*, 57(2), 18.

Coker, C. (2017). Water management for proposed Pittsgrove Twp. ASP composting facility. Report prepared for South Jersey Agricultural Products, Elmer, NJ, by Coker Composting and Consulting, Troutville, VA.

DECOS (2010). Endotoxins: Health-Based Recommended Occupational Exposure Limit. Dutch Expert Committee on Occupational Safety, Health Council of the Netherlands (DECOS) in Cooperation with the Nordic Expert Group for Criteria Documentation of Health Risks from Chemicals. Publication no. 2010/04OSH. https://www.healthcouncil.nl/documents/advisory-reports/2010/07/15/endotoxins-health-based-recommended-occupational-exposure-limit, accessed 1/9/20.

Domingo JL and Nadal M. (2009). Domestic waste composting facilities: A review of human health risks. Environment International 35(2):382-9.

Douglas, P., Bakolis, I., Fecht, D., Pearson, C., Leal Sanchez, M., Kinnersley, R., de Hoogh, K., and Hansell, A.L.. (2016). Respiratory hospital admission risk near large composting facilities. Int J Hyg Envir Heal. 219(4):372-9.

Douglas, P, Tyrrel, S.F., Kinnersley, R.P., Whelan, M., Longhurst, P.J., Hansell, A.L., Walsh, K., Pollard, S.J.T., and Drew, G.H. (2017) Predicting *Aspergillus fumigatus* exposure from composting facilities using a dispersion model: A conditional calibration and validation. International Journal of Hygiene and Environmental Health 220 (2017) 17–28.

Doyle, M. P. and Erickson, M. C. (2006). Closing the door on the fecal coliform assay. *Microbe*, 1(4), 162-163.

Environment Canada (2013). Technical document on municipal solid waste organics processing. Cat. no.: En14-83/2013E, https://www.ec.gc.ca/gdd-mw/3E8CF6C7-F214-4BA2-A1A3-163978EE9D6E/13-047-ID-458-PDF_accessible_ANG_R2-reduced%20size.pdf, accessed 1/10/20.

Federal Institute for Occupational Safety and Health. (2013) http://www.baua.de/de/Themen-von-A-Z/Biologische-Arbeitsstoffe/TRBA/TRBA-405.html BAuA. Technische Regel für Biologische Arbeitsstoffe 214 (Technical Rules for Biological Agents 214). Bundesanstalt für Arbeitsschutz und Arbeitsmedizin (Federal Institute for Occupational Safety and Health) accessed January 8, 2015.

Federal Institute for Occupational Safety and Health (2019) Technischen Regeln für Biologische Arbeitsstoffe (Technical Rules for Biological Agents) Das technische Regelwerk im Rahmen der Biostoffverordnung (The technical rulebook under the Biomaterials Regulation, in German.) https://www.abfallmanager-medizin.de/recht/technische-regeln-fuer-biologische-arbeitsstoffe-trba-das-technische-regelwerk-im-rahmen-der-biostoffverordnung/, accessed 07/03/19.

Finstein, M.S., Miller, F.C., Strom, P.F., MacGregor, S.T., and Psarianos, K.M. (1983). Composting Ecosystem Management for Waste Treatment. Bio/Technol. 1:347-53.

Finstein, M.S., Miller, F.C. and Strom, P.F. (1986a). Waste treatment composting as controlled system. In: Rehm, H.-J. and Reed, G. (eds.) *Biotechnology*, vol. 8, pp. 363-398. VCH Verlagsgesellschaft, Weinheim, Germany.

Finstein, M.S., Miller, F.C. and Strom, P.F. (1986b). Monitoring and Evaluating Composting Process Performance. J. Water Pollution Control Fed. 58:272-278.

Finstein, M.S., Miller, F.C., Hogan, J.A., and Strom, P.F.. (1987a, b, c, d). Analysis of EPA Guidance on Composting Sludge: Part I - Biological Heat Generation and Temperature, BioCycle 28(1):20-26; Part II - Biological Process Control, BioCycle 28(2):42-47; Part III - Oxygen, Moisture, Odor, Pathogens, BioCycle 28(3):38-44; and Part IV - Decomposition Rate and Facility Design and Operation, BioCycle 28(4):56-61.

Franke-Whittle, I. H. and Insam, H. (2013). Treatment alternatives of slaughterhouse wastes, and their effect on the inactivation of different pathogens: a review. *Critical Reviews in Microbiology*, 39,139–151.

Goldstein, N. (2015). Food scraps composting at yard trimmings site. *BioCycle*, 56(4), 21-22.

Golueke, C.G. (1977). *Biological reclamation of solid waste*. Rodale Press, Emmaus, PA.

Greene, K. L. and Tonjes, D. J. (2014). Degradable plastics and their potential for affecting solid waste systems. *WIT Transactions on Ecology and the Environment*, 180, 91-102.

Gurtler, J. B., Doyle, M. P., Erickson, M. C., Jiang, X., Millner, P., and Sharma, M. (2018). Composting to inactivate foodborne pathogens for crop soil application: A review. *Journal of Food Protection*, 81(11), 1821-1837.

Gutarowska, B, Skora, J., Stepien, L., Szponar B., Otlewska, A., and Pielech-Przybylska, K. (2015) Assessment of microbial contamination within working environments of different types of composting plants. J. Air Waste Manag. Assoc., 65, 466-478.

Harrison, E. Z. (2003). Compost Marketing and Labeling Project. Final report prepared to the New York State Energy Research and Development Authority. NYSERDA Report 6593. Cornell Waste Management Institute, Ithaca, NY.

Harrison, E.Z. and Krogmann, U. (2007). Guidelines for Application of Sewage Biosolids to Agricultural Lands in the Northeastern U.S. Rutgers NJ Agricultural Experiment Station, Bulletin E317. https://njaes.rutgers.edu/pubs/publication.php?pid=E317 , accessed 3/23/20.

Haug, R.T. (1993). *The practical handbook of compost engineering*. CRC Press, Inc., Boca Raton, FL.

Herr, C. E. W., zur Nieden, A., Bodeker, R. H., Gieler, U., and Eikmann, T. F. (2003). Ranking and frequency of somatic symptoms in residents near composting sites with odor annoyance. *Int. J. Hyg. Environ. Health*. 206:61–64.

Idaho Department of Environmental Quality. (2013). Processing (Composting) Facility Guidance and Checklists for Tier II and Tier III Processing Facilities. Retrieved from https://www.deq.idaho.gov/media/1078589-composting_guidance.pdf, accessed 1/9/20.

IFSC (Seven Generations Ahead & Illinois Food Scrap Coalition) (2015). Food Scrap Composting Challenges and Solutions in Illinois Report. Retrieved from https://sevengenerationsahead.org/images/work/zerowaste/IFSC-FoodScrapReportFINAL-Jan2015.pdf, accessed 9/1/19.

Kalaba, L., Wilson, B.G., and Haralampides, K. (2007) A stormwater runoff model for open windrow composting sites. Compost Science & Utilization 15(3): 142-150.

Kennedy/Jenks Consulting (2007). Compost leachate research. Report prepared for the Oregon Department of Environmental Quality, Land Quality Division.

Kern, M. (1991). Untersuchungen zur vergleichenden Beurteilung von Kompostierungsverfahren: Technik – Umweltrelevanz – Kosten. (Comparative evaluation of composting systems: technology – environmental relevance – costs: in German). In: Wiemer, K. and Kern, M. (eds.): Abfallwirtschaft: Bioabfallkompostierung – flächendeckende Einführung, pp. 235-278. Baeza Verlag, Witzenhausen, Germany.

Körner, I., Redemann, K. and Stegmann, R. (2005). Behaviour of biodegradable plastics in composting facilities. *Waste Management*, 25(4), 409-415.

Kramer, M. N., Kurup, V.P., and Fink, J.N. (1989). Allergic Bronchopulmonary Aspergillosis from a Contaminated Dump Site. Am. Rev. Respir. Dis. 140:1086-1088.

Kranert, M. (2000). Aerobe Verfahren (Kompostierung) Aerobic Systems (Composting). In: *Biologische Abfallverwertung (Biological Waste Treatment)*, Bidlingmaier, W. (ed.), pp. 56-119. Eugen Ulmer GmbH & Co., Stuttgart, Germany.

Krogmann, U., and Woyczechowski, H. (2000). Selected characteristics of leachate, condensate and runoff released during composting of biogenic waste. Waste Management & Research, 18(3), 235–248. doi: http://dx.doi.org/10.1177/0734242X0001800305

Krogmann, U., Boyles, L.S. and Heckman, J. (2001). Guidelines for the Land Application of Sewage Sludge for New Jersey Agriculture. Biosolids Working Group, Rutgers Cooperative Extension, Bulletin E228. https://njaes.rutgers.edu/pubs/publication.php?pid=E228, accessed 3/23/20.

Krogmann, U., Körner, I. and Diaz, L.F. (2010). Composting: Technology. In: *Solid Waste Technology and Management*, Christensen, T.H. (ed.), pp. 533-568. John Wiley & Sons, Chichester, UK.

Kühner, M. (2001). Planenkompostierung – Kompostierung unter semipermeablen Planenabdeckungen (Composting with covers – Composting under semipermeable covers: in German). In: Bioabfallkompostierung – Neue Entwicklungen and Lösungsmöglichkeiten zur Reduzierung von Geruchsemissionen. Hessisches Landesamt für Umwelt and Geologie, Wiesbaden, Germany.

Lampert, C. and Neubauer, C. (2015). Praxis grosser Kompostierungsanlagen und wesentliche Anforderungen an einen emissionsfreien Betrieb (Management practices of large composting facilities and main requirements for a low emission operation). Report REP-0501, Umweltbundesamt, Vienna, Austria.

Lenton, T.G. and Stentiford, E.I. (1990). Control of aeration in static pile composting. *Waste Management and Research*, 8, 299-306.

Lung, T. (2003). Ausbreitungsrechnungen und computergesteuerte Anlagenführung. (Dispersion calculations and computer-controlled plant management; in German). In: Microorganisms in the vicinity of waste treatment plants, Hessian State Office for the Environment and Geology, Wiesbaden. pp. 11-18. https://ip-lung.de/wp-content/uploads/2018/06/HLUG-03.pdf, accessed 1/31/20.

Marsh, P.B., Millner, P.D. and Kla, J.M. (1979). A guide to the recent literature on aspergillosis as caused by *Aspergillus fumigatus*, a fungus frequently found in self-heating organic matter. Mycopathologia 60: 67-81.

Mayer, J. (1990). Geruchsstoffe bei der Heißrotte von Hausmüll (Odorous compounds during composting of MSW at high temperatures). Ph.D. dissertation of the Department of Chemistry and Pharmacy at the Eberhard Karls Unversität Tübingen, Germany.

Miller, F.C., Harper, E.R. and Macauley, B.J. (1989). Field examination of temperature and oxygen relationships in mushroom composting stacks – consideration of stack oxygenation based on utilization and supply. *Australian Journal of Experimental Agriculture*, 29(5), 741-750.

Millner, P.D., Marsh, P.B., Snowden, R.B., and Parr, J.F. (1977). Occurrence of *Aspergillus fumigatus* during composting of sewage sludge. Applied and Environmental Microbiology 34: 765-772.

Millner, P.D., Bassett, D.A., and Marsh, P.B. (1980). Dispersal of Aspergillus fumigatus from Sewage Sludge Compost Piles Subjected to Mechanical Agitation in Open Air. Applied and Environmental Microbiology, 39:1000-1009.

Montgomery County (2018). Strategic Plan to Advance Composting, Compost Use, and Food Scrap Diversion in Montgomery County, Maryland. Montgomery County, Department of Environmental Protection, Division of Solid Waste Services, Rockville, MD.

Morrison Hershfield (2017). Best odour management practices at composting facilities, prepared for Metro Vancouver, http://www.metrovancouver.org/services/solid-waste/SolidWastePublications/Composting_Best_Practices_Study_Final_Report.pdf, accessed 1/10/20.

Müsken, J. (2001). Einfluß der Betriebsführung auf die Emissionscharakteristik einer Kompostierungsanlage (Effect of the Operation on the Emission Characteristic of a Composting Facility: in German). In: Bioabfallkompostierung – Neue Entwicklungen and Lösungsmöglichkeiten zur Reduzierung von Geruchsemissionen. Hessisches Landesamt für Umwelt and Geologie, Wiesbaden, Germany.

NJDOH (2016). Hazardous Substance Fact Sheet: Ammonia. NJ Department of Health. https://nj.gov/health/eoh/rtkweb/documents/fs/0084.pdf, accessed 3/18/20.

NYSDEC (2019a). Composting facilities. New York State Department of Environmental Conservation, 6 CRR-NY 361-3.2 https://govt.westlaw.com/nycrr/Document/Id4d62f22dfe911e7aa6b9b71698a280b?viewType=FullText&originationContext=documenttoc&transitionType=CategoryPageItem&contextData=(sc.Default)&bhcp=1 (accessed 7/10/19)

NYSDEC (2019b). Tables. New York State Department of Environmental Conservation, 6 CRR-NY 361-3.9 https://govt.westlaw.com/nycrr/Document/Id4d62f37dfe911e7aa6b9b71698a280b?viewType=FullText&originationContext=documenttoc&transitionType=CategoryPageItem&contextData=(sc.Default) (accessed 2/4/20)

NYSDEC (2019c). Regulations for Organic Recycling Facilities: brief summaries. New York State Department of Environmental Conservation, https://www.dec.ny.gov/chemical/97488.html#Composting (accessed 2/4/20)

Paré, M., Paulitz, T. C. and Stewart, K. A. (2000). Composting of crucifer wastes using geotextile covers. *Compost Science & Utilization*, 8(1), 36-45.

Pearson, C., Littlewood, E., Douglas, P., Robertson, S., Gan,t T.W., and Hansell, A.L. (2015). Exposures and health outcomes in relation to bioaerosol emissions from composting facilities: a systematic review of occupational and community studies. Journal of Toxicology and Environmental Health, Part B Crit. Rev. 18(1):43-69.

Pechan, E.H. (2004). Technical memorandum: MANE-VU 2002 ammonia emissions inventory for miscellaneous sources, final, prepared for the Mid-Atlantic Regional Air Management Association by E.H. Pechan & Associates, Inc. https://www.marama.org/visibility/Ammonia/Final_Tech_Memo.pdf, accessed 1/10/20.

Platt, B. (2016). Washington – Composting Rules. Institute for Local Self-Reliance. https://ilsr.org/rule/on-farm-composting/washington-3/, accessed 1/30/20.

Ramirez-Perez, J.C., Strom, P.F. and Krogmann, U. (2007). Horse Manure and Cranberry Fruit Composting Kinetics and Measures of Stability. *Compost Science & Utilization*, 15 200-214.

Recer, G.M., Browne, M.L., Horn, E.G., Hill, K.M., Boehler, W.F. (2001) Ambient air levels of Aspergillus fumigatus and thermophilic actinomycetes in a residential neighborhood near a yard-waste composting facility. *Aerobiologia* 17: 99–108.

Robertson S, Douglas P, Jarvis D, and Marczyloa E. (2019). Bioaerosol exposure from composting facilities and health outcomes in workers and in the community: A systematic review update. Int J Hyg Envir Heal. 222(3):364-86.

Roca-Barcelo, A., Douglas, P., Fecht, D., Sterrantino, A.F., Williams, B., Blangiardo, M., Gulliver, J., Hayes, E.T., and Hansell, A.L. (2019). Estimating *Aspergillus fumigatus* exposure from outdoor composting activities in England between 2005 and 14. Environ Res. [Nov 30: Epub ahead of print].

Rogers, B.F., Krogmann, U. and Boyles, L.S. (2001). Nitrogen mineralization of non-traditional organic wastes. *Soil Science,* 166(5), 353-363.

Rynk, R. (ed.) (1992). *On-Farm Composting Handbook*. Northeast Regional Agricultural Engineering Service, Ithaca, NY.

Seldman, N. (2014). Failure of the Wilmington composting facility underscores need for a locally based diverse composting infrastructure. https://ilsr.org/failure-wilmington-compost-facility-underscores-locally-based-diverse-composting-infrastructure/. Institute for Local Self-Reliance, Washington, DC.

Seven Generations Ahead & Illinois Food Scrap Coalition (IFSC). 2015. Food Scrap Composting Challenges and Solutions in Illinois Report. Retrieved from https://sevengenerationsahead.org/images/work/zerowaste/IFSC-FoodScrapReportFINAL-Jan2015.pdf, accessed 9/1/19.

SJVAPCD (San Joaquin Valley Air Pollution Control District) (2010). Compost VOC emission factors. September 15, 2010, https://www.valleyair.org/busind/pto/emission_factors/Criteria/Criteria/Composting/Compost%20EF.pdf, accessed 1/10/20.

Storino, F., Arizmendiarrieta, J. S., Irigoyen, I., Muro, J. and Aparicio-Tejo, P. M. (2016). Meat waste as feedstock for home composting: Effects on the process and quality of compost. *Waste Management*, 56, 53-62.

Strom, P.F., Morris,, M.L., and Finstein, M.S. (1980). Leaf Composting through Appropriate, Low-Level Technology. Compost Sci. 21(6):44-8.

Strom, P.F., Flower, F.B., Liu, M.H.P., and Finstein, M.S. (1986). Municipal Leaf Composting: Recommended Methods. BioCycle 27(9):48-52.

Strom, P.F. and Finstein, M.S. (1994). New Jersey's Manual on Composting Leaves and Management of other Yard Trimmings. New Jersey Department of Environmental Protection, 81pp. http://www.nj.gov/dep/dshw/rrtp/compost/cptitle.htm

Sundberg, C., Yu, D., Franke-Whittle, I., Kauppi, S., Smårs, S., Insam, H., Romantschuk, M. and Jönsson, H. (2013). Effects of pH and microbial composition on odour in food waste composting. *Waste Management* 33(1), 204-211.

Tetra Tech, Inc. (2002). Commercial Food Waste Composting Study. Project report prepared for Oregon Department of Environmental Quality, Land Quality Division, Solid Waste Program.

Tonjes, D.J., Rapiejko, A., and Norgard, J. (2018). When compost does bad things to groundwater. Conference Proceedings, The Federation of New York Solid Waste Associations (https://nyfederation.org/2018-proceedings/), https://nyfederation.org/wp-content/uploads/2018/pdf2018/69%20TonjesD.pdf, accessed 2/5/20.

TMECC (2002). Test Methods for the Examination of Composting and Compost. U.S. Composting Council, Bethesda, MD.

U.K. Environment Agency (2018a). Bioaerosol Monitoring at Regulated Facilities - Use of M9: RPS 209. https://www.gov.uk/government/publications/bioaerosol-monitoring-at-regulated-facilities-use-of-m9-rps-209/bioaerosol-monitoring-at-regulated-facilities-use-of-m9-rps-209, accessed 1/9/20.

U.K. Environment Agency (2018b). Environmental Monitoring of Bioaerosols at Regulated Facilities. Technical Guidance Note (Monitoring) M9. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/730226/M9_Environmental_monitoring_of_bioaerosols_at_regulated_facilities.pdf, accessed 1/9/20.

United Nations Environment Programme (UNEP) (2019). (https://www.unenvironment.org/thinkeatsave/about/definition-food-loss-and-waste)

US Composting Council (2019). Compost STA. https://www.compostingcouncil.org/page/CertifiedCompostSTA (accessed 11/23/19).

USEPA (1981). *Composting processes to stabilize and disinfect municipal sewage sludge*. EPA 430/9-81-011. Office of Water Program Operations, United States Environmental Protection Agency, Cincinnati, OH.

USEPA (2018). Title 40, Code of Federal Regulations, Part 503: Standards for the Use or Disposal of Sewage Sludge. https://www.govinfo.gov/content/pkg/CFR-2018-title40-vol32/pdf/CFR-2018-title40-vol32.pdf.

USEPA (2019a). Sustainable Management of Food. https://www.epa.gov/sustainable-management-food/sustainable-management-food-basics#targetText=Food%20waste%20refers%20to%20food,%20or%20combusted%20with%20energy%20recovery. United States Environmental Protection Agency, accessed 1/9/20.

USEPA (2019b). Advancing Sustainable Materials Management: 2017 Fact Sheet. United States Environmental Protection Agency, EPA 530-F-19-007. https://www.epa.gov/sites/production/files/2019-11/documents/2017_facts_and_figures_fact_sheet_final.pdf, accessed 1/9/20.

USGS (undated). Oxidation/reduction (redox). Water Resources, US Geological Survey. https://www.usgs.gov/mission-areas/water-resources/science/oxidationreduction-redox?qt-science_center_objects=0#qt-science_center_objects, accessed 3/19/20.

Vaccari, D.A., Strom, P.F. and Alleman, J.A. (2006). *Environmental biology for engineers and scientists.* John Wiley & Sons, Inc., Hoboken, NJ.

Vidussi, F. and Rynk, R. (2001). Meat byproducts as composting feedstocks. *BioCycle,* March, 71-74.

Vincken, W., and Roels, P. (1984). Hypersensitivity pneumonitis due to *Aspergillus fumigatus* in compost. Thorax. 39:74-75.

WAC (2018a). Composting Facilities. Washington Administrative Code 173-350-220. https://apps.leg.wa.gov/wac/default.aspx?cite=173-350-220, accessed 1/30/20.

WAC (2018b). Performance Standards. Washington Administrative Code 173-350-040. https://apps.leg.wa.gov/wac/default.aspx?cite=173-350-040, accessed 1/30/20.

WDEQ (2004). "Guidance Manual for Preparing/Updating a Stormwater Pollution Prevention Plan for Industrial Facilities, Washington Department of Ecology, Publication Number 04-10-030.

Wichuk, K.M. and McCartney, D. (2010). Compost stability and maturity evaluation – a literature review. Can. J. Civ. Eng. 37: 1505–1523.

Williams, B, Douglas, P, Roca-Barcelo, A, Hansell, A.L., and Hayes, E. (2019). Estimating *Aspergillus fumigatus* exposure from outdoor composting activities in England between 2005 and 14. Waste Manag. 84: 235-244.

Wilson, B.G., Haralampides, K., and Levesque, S. (2004). Stormwater runoff from open windrow composting facilities. J. Environ. Eng. Sci. 3: 537-540.

Zwerling, E. and Strom, P.F. (1992). Viable *Aspergillus fumigatus* spores aerosolized from yard waste composting. Report submitted to NJDEP, Office of Recycling and Planning, Trenton, NJ

Appendix 1. Food composting project overview prepared by the SRWMP

ISSUE: Outdoor Food Waste Compost Operations. What are the Potential Impacts to groundwater and air from outdoor food waste composting? What is the best recipe for composting of food waste? What buffer do you need around these facilities?

BACKGROUND:

- Source separated food waste is a Class C recyclable material. Composting of food waste requires a Class C recycling general approval.
- In the past, there was a handful of food waste compost facilities in NJ, but all of them closed due to operational problems. Some created odor nuisance as well as leachate problems.
- Currently there are no operating Class C food waste compost facilities in NJ, only one Research, Development, and Demonstration (RD&D) facility operating (a second was permitted by DSHW but is awaiting permits from other Programs in DEP).
- Because of past contamination issues, Air permitting (odor) and Water permitting (surface/groundwater) have become major hurdles for such facilities.

INFORMATION NEEDED*:

a. Need scientific data based on research and studies to determine potential adverse impact on human health and the environment from odors and leachates.
    i. Need recommended recipe (C:N ratio) including addition of dairy/meat products and other practices to enhance composting process and minimize odor.
b. Need recommended liner (if any) material for the compost bed including leachate control to minimize impacts on surface/groundwater.
c. Need comparative study for various compost methods (traditional windrows, static/forced aeration, etc.) and recommended method for outdoor food waste composting.
d. Need appropriate tests to determine nutrients and contaminants in the final compost product.

JUSTIFICATION: See background.

*These are the original program needs provided at the initiation of the project. During the course of the work, these needs were modified/expanded in response to the developing information. The revised needs are presented in Appendix 2.

Appendix 2: Revised Program Information Needs

In addition to the above charge questions, the SRWP requested that the Work Group provide a scientific basis for the following information needs. Although information needs (Appendix 1) were presented at the onset of the Work Group's deliberation, modified/expanded needs became apparent during the course of this project. Corresponding scientific information for each numbered bullet can be found throughout the report.

1) Recommended recipes (e.g., carbon to nitrogen ratio, C/N) including addition of dairy/meat products and other practices to enhance the composting process and minimize odor (discussed in Section 5).
2) Comparisons of various composting methods (e.g., traditional windrows, static piles with forced aeration) and recommended methods for outdoor food waste composting (Section 6).
3) Appropriate tests to determine nutrients and contaminants in the final compost product (Section 7).
4) Scientific data on potential adverse impacts on human health and the environment from leachate and runoff, and recommended leachate control practices (including liner, if any), to minimize impacts on surface and groundwater (Section 8).
5) Scientific data on potential adverse impacts on human health and the environment from air emissions, including odors and biological aerosols (Sections 9 and 10).
6) Comparative studies of impacts associated with various **types** of food waste that are composted (Section 5).
7) Comparative studies of various **sizes** of composting facilities to determine relative environmental risks from each (Section 12).
8) Recommended tiers based on size and type of composting materials based on (6) and (7) above. An ultimate objective would be to provide an exemption from permitting or reduce permitting requirements for smaller facilities treating less problematic materials (Section 12).