Survey of Large Commercial Compost Facilities in Washington

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List of Abbreviations

CARB	California Air Resources Board
CASP	covered aerated static piles
cfm/CFM	cubic feet per minute
C/N	carbon to nitrogen ratio
CO_2	carbon dioxide
ECS	Engineered Compost Systems
EPA	Environmental Protection Agency
GMT	Green Mountain Technology
HAP	hazardous air pollutant
JEE	Jumelet Environmental Engineering
lbs/cy	pounds per cubic yard
m^3	cubic meter
NH_3	ammonia
PRFP	Process to Further Reduce Pathogens
TAP	toxic air pollutant
µg	microgram
VOC	volatile organic compound
WSU	Washington State University

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Executive Summary

As an initial step to support the development of methodologies for appropriately measuring emissions from diverse Washington composting facilities, the ten largest commercial composting facilities in Washington were surveyed (one of the ten declined to participate). One smaller facility was also surveyed, as it will be the site of future field testing of volatile organic compound (VOC) air emissions measurement methodologies. Facilities were asked about their feedstocks, composting processes, and air emissions mitigation technologies. Primary findings from the survey included the following:

- Only one facility operated as turned windrow. Most facilities used aeration; turned aerated piles was a common practice (4 facilities).
- Nine of the ten facilities that participated in this survey have mechanical aeration systems. This includes systems that run only as positive aeration (2 facilities), only as negative aeration (4 facilities), or as an air flow reversing system (3 facilities) whereby the air flow is sometimes positive, sometimes negative, or off. Sometimes different phases of the composting process vary in the aeration that is practiced.
- Three broad groupings in terms of process types were identified: turned windrows with no mechanical forced aeration, Gore fabric covered positively aerated piles, and uncovered aerated piles. The most common process type was uncovered aerated piles using either negative aeration (3 facilities), positive aeration (1 facility), or reversing aeration (2 facilities).
- Two facilities have aeration systems designed by Green Mountain Technology. Five facilities have systems designed by Engineered Compost Systems. Two facilities have systems designed by Jumelet Environmental Engineering (with involvement of the compost company).
- Eight of the ten facilities surveyed have a biofilter. Two facilities utilize Gore covers. Some compost facilities cover the pile with overs (4 facilities) or with finished compost (2 facilities) (though exactly where in the process this covering occurs varies by facility).
- Feedstocks varied between facilities and seasonally. The most common seasonal variation noted was that facilities with a large percentage of yard waste or mixed food/yard waste reported an influx of grass during March or April through June and an influx of grass and leaves in the fall. Seasonal variation in agricultural waste products (e.g., cherries, pears, apples, grape pomace, pumpkins) was noted by some facilities. One facility mentioned moisture as being significantly different by season. Facilities have strategies for adjusting feedstock mixes (e.g., incorporating more woody materials during the spring when there are increases in nitrogen rich high-moisture feedstocks such as grass) to compensate for these seasonal changes.
- Process parameters varied somewhat between facilities, and have not been summarized, as those are most relevant within in the context of the composting process at each individual facility.

Air sampling for determining VOC emission rates will have to be modified to sample air from negative aerated piles and reversing air flow aeration systems. The current method of using surface flux isolation chambers could work for sampling diffusive emissions from windrows, and positively aerated piles, but would miss VOC emissions being pulled from the piles under negative aeration flow.

To aid the Washington Department of Ecology (Ecology) in their efforts to develop methodologies for measuring emissions from Washington State composting facilities, we have provided a preliminary sketch in Appendix G: Emissions Sampling Considerations. This information could form the basis of further discussions with a variety of stakeholders to develop an emissions sampling plan for Washington State.

Introduction

The Washington State Department of Ecology (Ecology) contracted with Washington State University to help with initial steps to support the development of methodologies for measuring emissions from composting facilities that are appropriate for the diversity of commercial composting facilities in Washington. The goal of this study is to better understand the variability in these facilities that affect emissions, namely feedstocks (including variation by season), processes used, and mitigation technologies used. The facilities in this study included the 10 largest commercial composting facilities in the state and one facility that is of particular interest because it will be the site of field testing by Washington State University (WSU) researchers. Ecology contacted representatives of the composting facilities of interest to let them know about the study in late 2019. The WSU team followed up with representatives from these facilities by email and phone, sent the survey question document (Appendix A), and set up phone interviews to discuss the questions during January 2020.

The data collected in this project included both information from publicly available documents (e.g., permit documents filed with Ecology and documents filed with local health jurisdictions) and voluntary interviews (Facilities 1-8, 10-11). The information will be used by the WSU team to strengthen their understanding of the organics compost industry in Washington State, and to inform their recommendations for the design of a possible future Ecology field study of large commercial facilities in Washington. Participation in this study was voluntary. Facility 9 declined to participate. Facilities are referenced by number, rather than name, to protect potentially sensitive information.

Responses to Survey Questions

Feedstock Mix

Information on feedstocks were obtained from annual reports submitted to Ecology for 2017 (Table 1).

Table 1: Feedstocks reported by each of the facilities in this study for 2017. Source: Washington State Department of Ecology. Note that the categories used by Ecology do not always match up with feedstock categories used by the composters.

	Facility										
Feedstock type (tons)	1	2	3	4	5	6	7	8[a]	9	10	11[b]
Agricultural Organics	6,676		3,629				200	210			
Biosolids (dry tons)							3,784				
Food processing waste	4,239		43,729				1,678				
Food waste, post-consumer	37						109	262			
Food waste all other (incl. pre-consumer food)			1,366	83		126	741	66		16,077	70,566
Industrial organics							10,194				
Land-clearing debris	204	266		1		415			26,649	266	3,885
Manure with bedding				83		1,358		9,356			
Mortalities								90			
Sawdust and shavings							6,792				88
Other wood debris	125						3,212	1,038		4,330	4,971
Yard debris food scraps	19,934				66,702		58,878			106,149	136,397
Yard debris	5,333	42,579	962	63,871	6,657	72,041	115	371	27,402	13,003	15,732
Facility Total (tons)	36,548	42,845	49,686	64,038	73,359	73,940	85,703	11,393	54,051	139,825	231,639

[a] Facility 8 has significantly lower total feedstock numbers than the other facilities described in this report, but was included in this report because it will be the site of field experimentation for developing methodology.

[b] See Appendix C for detail on monthly variability in feedstocks for Facility 11.

To supplement this information, representatives from the facilities participating in interviews were asked the following questions:

Please describe how much variability exists in the composition of these feedstocks by month (composition and relative quantity).

Is there a time of year that you think the feedstocks vary enough that it could affect emission rates significantly?

Table 2: Feedstock responses.

Facility	Seasonal variation in feedstocks	Is there a time of year that emissions may vary significantly due to feedstocks?
1	This facility accepts feedstocks including the following, which show seasonal variation: yard debris and yard debris/food scraps (mixed)– April – June: lots of grass Sept – Jan: lots of leaves fruit waste Jun-Jul: cherries Jan-spring: pears and apples	Spring grass season (April – June)
2	Mar – Jun is busy for yard waste (grass clippings), seasonal dip in July and August, Second growing season in Sept & Oct Nov there is a big influx of leaves	Every facility in WA state has more N coming in in April, May, and June
3	Grape pomace – get bulk of it in Sept - Nov Not much seasonal variation due to yard waste because it is only 20-25% of feedstocks	Possibly in the fall due to grape pomace, sugars and lower pH makes piles heat up faster
4	Mar – Jun is busy for yard waste (grass clippings), seasonal dip in July and August, Second growing season in Sept & Oct Nov there is a big influx of leaves	Every facility in WA state has more N coming in in April, May, and June. This facility accepts a small amount of food waste and manure waste.

Facility	Seasonal variation in feedstocks	Is there a time of year that emissions may vary significantly due to feedstocks?
5	Nitrogen-rich vegetative feedstocks in the spring and fall (such as grass clippings in the spring, pumpkins in the fall) can occur for relatively short periods of time in quantities sufficient to warrant changes to feedstock processing. Incoming tonnage variability is primarily influenced by feedstock generator volumes and moisture content of the feedstocks. Incoming tonnage variability is primarily controlled through contractual agreements and functional capacity at the site. Seasonal quantitative variabilities at our site can increase feedstock availability up to 30% in the spring and fall during years with significant precipitation and extended dry periods if not controlled through contractual arrangements. During years without these environmental conditions, feedstock availability varies as little as 10%.	These variables have little influence on annual emissions generated from the composting process if proper operating procedures are followed (see mixing process below) and because the duration of these events occurs over a relatively short timeframe. Nitrogen-rich high-moisture feedstocks such as grass are balanced in the feedstock mix by incorporating more woody materials. High carbon sources are balanced by adding nitrogen-rich feedstocks. The CASP system reaches thermophilic temperatures quickly so moisture is further balanced in a relatively short time frame through the evaporative process as needed. (More detail in Appendix B)
6	Mar – Jun is busy for yard waste (grass clippings), seasonal dip in July and August, Second growing season in Sept & Oct Nov there is a big influx of leaves	Every facility in WA state has more N coming in in April, May, and June
7	Grass percentage goes up for second half of June, July, August and September. During this time, more wood waste that they have stockpiled ahead of time is added into the mix.	Possibly in the early summer due to more grass and vegetative waste.
8	Seasonal effect is mostly more moisture. Majority of material is in the wintertime and it tends to be wet. Ideally you would like your compost to start at 65% moisture Wet season typically runs Nov-March Dry season typically July-Sept	Yes, summer vs winter is a significant difference. Maybe not the amount of emissions as much as the type due to the moisture and the amount of manure we receive during the winter.

Facility	Seasonal variation in feedstocks	Is there a time of year that emissions may vary significantly due to feedstocks?
10	The annual feedstocks shown are verified. There is variability to the feedstocks by month in terms of density (e.g., wet v. dry material) and composition (seasonal). The peak seasons are typically spring, with significant amounts of yard waste, and also fall, due to leaves. Food waste and associated packaging remain somewhat consistent at lower levels throughout the year so the percentage either goes up or down based on the amount of greenwaste coming in. Major storms with high winds can often result in higher levels of feedstocks for a short time after the storm.	A high content of wet grass in the compostable materials results in batches that are too dense to draw oxygen to decompose aerobically. To preclude this event, significant bulking agent is added to the fresh waste to achieve sufficient porosity, structure, and carbon.
11	See Facility 10	See Facility 10

Please describe mixing process – what defines a good mix and how is mixing performed?

Table 3: Mixing process responses.

Facility	Response
1	Mixed with a loader
2	Operators determine a good mix Loader starts everything out, goes through grinder, row turner Everything comes in pre-ground, always have a stockpile of extra carbon they can add if they need to, but don't have to add at this facility due to land clearing debris.
3	Drivers for the windrow, layering materials as they bring it in and windrow turner is used to make a mix
4	Accepts some material that is already ground (which is ground and mixed at another facility run by the same company), additional material is ground and mixed with front end loader.
5	We use a combination of a screening process, a horizontal grinder, and a loader to physically mix and handle feedstocks for the composting process. The trained compost operator defines and re-adjusts the final mix as necessary to achieve the desired results.
6	Mixing involves Vermeer TG7000 tub grinder, excavator, loader; receiving area is under covered roof, conveyer is discharged inside of building onto green mulch pad (positively aerated), will add C if need to then pack into mass bed.
7	A formula is followed for feedstocks to make mix, do a little bit of bucket mixing with front end loader then mix with windrow turner about 4 times to mix.
8	4 auger 15 CY mixer. Put in preset amount using loader bucket. Mixer runs for about 20 minutes.
10	Grinder or other designated processing equipment loaded with appropriate quantities of feedstock to grind and mix prior to discharge.
11	See Facility 10

What is the typical range of density in pounds per cubic yard (lbs/cy), carbon to nitrogen (C/N) ratio, and percent moisture of the initial feedstock mix that the facility encounters throughout the year?

Table 4: Characteristics of initial feedstock mix.

Facility	Density (lb/cy)	C/N ratio	Percent moisture	Additional information
1	1000 lbs/cy	25:1-30:1	range of 45-65%	20% of initial mix is overs for bulk density 60% porosity for each newly built windrow measured using 5 gal bucket test Moisture readings taken throughout the composting process, using the 'hand squeeze' moisture test, to maintain the 55% moisture target.
2	<1000 lbs/cy	25:1-40:1	65%	
3	850-1000 lbs/cy	C/N about 25:1 (range 20:1-40:1)	moisture 35-40% (start low so can add liquid/high moisture feedstocks early in the process to bring moisture up to 45%-55%)	free air space 35-60%
4	below 1000 lbs/cy	25:1-40:1	65%	
5 (see App B for more detail)	30% free air space, typically 950 lbs/cy	20:1-40:1	40-60%	

Facility	Density (lb/cy)	C/N ratio	Percent moisture	Additional information
6	below 1000 lbs/cy	25:1-40:1	65%	
7	900-1100 lbs lbs/cy		55-65% moisture	
8	1000 lbs/cy	avg 40:1	Start at 65% moisture and hope you still have 40% by the end of the mixing process.	
10		Between 20:1 and 35:1	60%	Seasonal variation requires extra bulking or material high in carbon to balance out the incoming feedstocks. (10% - 30% bulking agent is used depending on season.)
11		Between 20:1 and 35:1	approximately 55% in negative air, 60% in Gore Cover System.	See Facility 10

Process

Please describe the composting process(es) used at your facility, in terms of type of system, size of piles, aeration- forced (negative and/or positive and air throughput) or passive, and pile temperature. When there are separate systems, please describe each separately and estimate the percentage of total material at the facility that is run through each process.

Please describe the process at each stage (for example, active composting, compost stabilization, curing) using the table below. If there is a portion of your waste stream which is kept entirely separate and run through a different set of processes, please describe that separately.

Note: While the stages of "active composting," "stabilization" and "curing" were listed as examples for composters to use, the stages were not defined in the survey. Some definitions for these are offered in Appendix E.

Table 5: Facility 1 process details.

	Active Composting	Stabilization/Curing
Typical length of process (days)	21 days, Turn twice a week	Move 25 ft away, unaerated mass bed, turned once/week 69 days (average)
Average High Temp	Controlled effectively with aeration and kept close to 145°	Front of cure can get up to 150° Back can be down at 110°
Average Temp	average 145°	average 145°
Average % Oxygen	Controlled by managing bulk density & aeration, not regularly measured	Controlled by managing bulk density & aeration, not regularly measured
Average pH	Don't measure regularly	Don't measure regularly
Average Pile Depth	8 foot	8 foot
Average Aeration Rate (cfm/cy)	Design spec 4.2 (high) 2.0 (low) first half on higher, second half on lower	Not aerated (passive aeration)
Aeration Mode (positive, negative, reversing)	Negative aeration except during turning.	Not aerated (passive aeration)

Table 6: Facility 2 process details. Mass bed positively aerated system. Process can be as short as 32 days.

	Phase 1	Phase 2
Typical length of process (days)	15-25 days, turned using Vermeer side turner, turned every 3-5 days	~15 days
Average High Temp		
Average Temp	50-60 C	~ 45 C
Average % Oxygen	15% (past measurement, not regularly measured)	
Average pH		
Average Pile Depth	12 ft	
Average Aeration Rate (cfm/cy)		
Aeration Mode (positive, negative, reversing)	Positive	Positive

Table 7: Facility 3 process details. Turned windrow system, no active aeration.

	Active Composting	Stabilization	Curing
Typical length of process (days)	30 days (in order to meet PFRP while being able to add liquid feedstocks), typically about 7 turns	30 days – monitoring them for moisture, maybe doing a couple of turns if needed for moisture	30-60 days
Average High Temp	170 max		
Average Temp	155 avg	125-130	100-110
Average % Oxygen	unknown	unknown	unknown
Average pH	unknown	unknown	unknown
Average Pile Depth	7 ft	7 ft	7 ft
Average Aeration Rate (cfm/cy)	N/A	N/A	N/A
Aeration Mode (positive, negative, reversing)	N/A	N/A	N/A

Table 8: Facility 4 process details. Aerated mass bed (42-45 days for whole process); Whole process takes place in semi-enclosed building.

	Phase 1	Phase 2
Typical length of process (days)	15 days (turned 5 times)	30 days (moved from one zone to another after 15 days)
Average High Temp	65	
Average Temp	55	50
Average % Oxygen		
Average pH		
Average Pile Depth	12 ft (9-10 ft after settling)	9-10 ft
Average Aeration Rate (cfm/cy)		
Aeration Mode (positive, negative, reversing)	Reversing	Negative, comp dogs

Table 9: Facility 5 process details. See Appendix B for more detail.

	Active Composting	Stabilization	Curing
Typical length of process (days)	8-15 days	45-60 days	Variable depending upon desired results
Average High Temp	65 Celsius	55 Celsius	45 Celsius
Average Temp	55 Celsius	45 Celsius	20 Celsius
Average % Oxygen	Residual oxygen above microbial consumption requirements	Residual oxygen above microbial consumption requirements	Residual oxygen above microbial consumption requirements
Average pH	6.0-8.0	6.0-8.0	6.0-8.0
Average Pile Depth	10 feet	10 feet	20 feet
Average Aeration Rate (cfm/cy)	2.0	See Reference 1.	See Reference 1.
Aeration Mode (positive, negative, reversing)	Positive, negative, reversing, passive	Natural inflow and convection	Natural inflow and convection

Reference 1. Airflow measurement in passively aerated compost. Yu, O.G. Clark and J.J. Leonard*

Table 10: Facility 6 process details. Whole process takes 28-40 days.

	Phase 1	Phase 2
Typical length of process (days)	15-21 days, turned 5 times, insulating layer of overs added for middle 3 days	7-15 days Not turned
Average High Temp	65	
Average Temp	55	45
Average % Oxygen		
Average pH		
Average Pile Depth	12	12
Average Aeration Rate (cfm/cy)		
Aeration Mode (positive, negative, reversing)	Reversing	Positive

Facility 7

Two separate feedstock streams are processed at this facility:

Mix including biosolids/paper sludge: 15 days primary aeration (static pile), then moved to another location 15 days secondary aeration (static pile), then moved again for 15 days curing (sitting in a windrow with no turning or aeration), then put into windrows as prescreened finished product

Green waste only mix: ground, 20 days primary aeration (static pile), then moved to another location for 25 days secondary aeration and curing (static pile), then moved to windrow for 20-30 days (aerated by turning a couple of times a week)

Table 11: Facility 7 process details.

	Active Composting	Stabilization	Curing
Typical length of process (days)	24 days	2-4 months	1-6 months
Average High Temp	170 F	155 F	140 F
Average Temp	160 F	140 F	130 F
Average % Oxygen	Not monitored	Not monitored	Not monitored
Average pH	8.6	8.6	8.6
Average Pile Depth	8’	7’	10’
Average Aeration Rate (cfm/cy)	15 cfm	NA	NA
Aeration Mode (positive, negative, reversing)	Negative	Passive	Passive

Facility 10

GORE Cover System with positive aeration (100% of total feedstocks)

- Description = 3 Phase Covered Positive Aeration Composting process (Ph 1 and 2 use Gore covers).
- Phase 1 pile size = 160'L x 25'W x 9'H
- Secondary pile size = 160'L x 25'W x 9'H
- Temperature range = 80-185F

Table 12: Facility 10 process details.

	Active Composting	Stabilization	Curing
Typical length of process (days)	Phase 1 (21-28 days) and 2 (14 days)	Phase 3 (14 days)	Stored/stockpiled until sale
Average High Temp	170F	160F	140F
Average Temp	160F	150F	Ambient-100F
Average % Oxygen	8-14%	8-14%	<10%
Average pH	5-7	5-7	5-8
Average Pile Depth	9'	9'	25-50'
Average Aeration Rate (cfm/cy)	Aeration is intermittent based on operating system controls 2.5 hp aeration for average of 25% of the time longer at beginning shorter at end. .5 hp per 1000 cubic yards.	2.5 hp aeration for average of 25% of the time longer at beginning shorter at end. .5 hp per 1000 cubic yards.	
Aeration Mode (positive, negative, reversing)	Positive	Positive	None added

Facility 11

This facility has 3 systems:

I. **Hybrid negative air system (72% of total)**
   - Description = 3-Phase Negative Aeration Compost process including 1’ of wood/overs cover in Phase 1.
   - Primary pile size = 160’L x 90’W x 17’H
   - Secondary pile size = 180’L x (32’W x 128’W) x 14’H
   - Temperature range = 80-195F

II. **Enclosed negative air system (10% of total)**
   - Description = 3-Phase Negative Aeration Compost process (Phase 1 in building enclosure)
   - Phase 1 pile size = 100’L x 100’W x 15’H
   - Secondary pile size = 180’L x (32’W x 128’W) x 14’H
   - Temperature range = 80-185F

III. **GORE Cover System with positive aeration (18% of total)**
   - Description = 3 Phase Covered Positive Aeration Composting process (Phase 1 and 2 use Gore covers)
   - Phase 1 pile size = 160’L x 25’W x 9’H
   - Secondary pile size = 160’L x 25’W x 9’H
   - Temperature range = 80-185F

Table 13: Facility 11 process details.

	Active Composting (Phase 1 and 2)	Stabilization (Phase 3)	Curing
Typical length of process (days)	Neg. Air: Phase 1 (16-30 days) and Phase 2 (16-30 days) GCCS: Phase 1 (28 days) and Phase 2 (14 days)	Neg. Air: Phase 3 (16-25 days) GCCS: Phase 3 (14 days)	Stored/stockpiled until sale
Average High Temp	Neg. Air 160F GCCS 170F	Neg. Air 150F GCCS 160F	Neg. Air 140F GCCS 140F
Average Temp	Neg. Air 157F GCCS 160F	Neg. Air 142F GCCS 150F	Neg. Air Ambient-100F GCCS Ambient-100F
Average % Oxygen	8-14%	8-14%	<10%
Average pH	5-7	5-7	5-8
Average Pile Depth	Neg. Air 14' GCCS 9'	Neg. Air 14' GCCS 9'	Neg. Air 25-50' GCCS 25-50'
Average Aeration Rate (cfm/cy)	Neg. Air 5 cf/cf.hr. GCCS *see below*	Neg. Air 2 cf/cf.hr	N/A
Aeration Mode (positive, negative, reversing)	Neg. Air Negative GCCS Positive	Neg. Air Negative GCCS Positive	Neg. Air Negative GCCS Positive

Aeration Systems

What type of aeration system do you have (and which company designed it)? For systems that are set up for both negative and positive aeration, what are the parameters that determine whether negative or positive aeration is used? What percentage of time (estimated) is positive aeration used in these systems and how does this vary by season?

Table 14: Aeration system details.

Facility	Type of aeration system	Negative/Positive/Reversing	Additional information
1	Green Mountain Tech.	Running on negative aeration most of the time to a biofilter, but running on positive aeration during turning to prevent clogging of sparger	Have not had good success with not turning during active composting because of feedstock mix. Stockpiling is different than some other facilities. Turned mass bed in active composting and in curing phase. There is lots of turning – material is turned 17 times during the process.
2	ECS	Positive	Positive aeration running all the time is delivered through 4-inch pipes imbedded at grade in concrete troughs 8 feet on center with 5/8-inch holes 4 feet on center. 8 separate aeration zones controlled with dampers (4 in compost building and 4 in curing building)
3	N/A – no aeration system, turned windrows		

Facility	Type of aeration system	Negative/Positive/Reversing	Additional information
4	ECS	Phase 1: Reversing (estimate 40/60 negative/positive) Phase 2: Negative	For Phase 1, aeration reverses if there is a temp gradient of 5 C between to top and bottom. Not much seasonality to the split, maybe on negative air more in winter
5	ECS	for Phase 1 composting only. Can run as positive/negative/reversing	In the reversing air mode, directional air change occurs when the invert temperature differential between the top and bottom temperature probes reach the invert setpoint (determined by the certified compost operator. Currently, the amount of time that the system spends in different modes is typically 40% positive, 40% negative and 20% quiescent. NOTE: due to regulatory reasons Facility 5 will likely be operating the system in a negative only mode. This change will significantly alter the sampling methodology for the site.
6	ECS	Phase 1: Reversing Phase 2: Positive	

Facility	Type of aeration system	Negative/Positive/Reversing	Additional information
7	ECS	Negative only	2 temperature probes per pile, goal is to keep piles under 160F. 1 damper per zone, 20 zones total (10 zones in each primary and secondary aeration) First 15 days, air flow is close to 100%, after pile starts to cool a bit then dampers ramp down. Fan runs at about 70% capacity. Both primary and secondary aeration are on negative aeration only
8	Green Mountain Tech.	This system is set up to run on either positive or negative aeration, but is always running negative aeration.	Large fan that pulls air, each of the 12 zones has a control regimen that is feeding the systems temperature data. Tells the damper whether to open or close. Fan is on PLC (variable speed control). System monitors fan capacity and duct pressures. There could be a port put between pile and damper to monitor each pile individually. There are some existing ports for sampling – including one before the fan.
10	GORE Cover System was designed by W.L. Gore & Associates and UTV/AG.	Negative air system for receiving/grinding building where feedstocks are received, blended and shredded. Positive (Gore Cover System)	

Facility	Type of aeration system	Negative/Positive/Reversing	Additional information
11	Negative air systems were designed by Jumelet Environmental Engineering and by the company that owns this facility. GORE Cover System was designed by W.L. Gore & Associates and UTV/AG.	Negative for all three phases of Negative Air System Gore Cover System: Positive air system	

Emission Mitigation Strategies

Please describe any emission mitigation strategies that are used in the composting process, for example:

- **use of Gore Covers**
- **covering with compost overs**
- **use of biofilters (see question below)**
- **receiving area enclosure (see question below)**
- **maintaining oxygen levels above 13% throughout the process**
- **maintaining moisture levels between 45% and 55%**
- **reducing turning if aerated, or increasing turning if not aerated**
- **management of bulk density**

All facilities manage processes parameters (e.g., moisture levels, oxygen levels and bulk density), which also minimizes emissions. The table below shows *additional* strategies that each facility representative mentioned. Note that not mentioning process parameters does not necessarily mean that a given facility *doesn't* use those parameters, just that they weren't brought up explicitly in the conversation.

Table 15: Additional strategies for emission mitigation, all facilities.

Facility	Response
1	• Active compost not capped because it is turned twice a week • "Battery" stockpile of feedstock usually sits for a month before mixing and is covered with 12" cap of overs • Biofilter
2	• Management of bulk density, moisture levels and aeration
3	• Maintaining pore space through feedstock mixing • Maintaining moisture levels between 45% and 55% • Management of bulk density
4	• Biofilter
5	• Feedstocks are processed on demand to minimize stockpiling emissions. • The receiving (tipping) building is partially enclosed and has a high-volume air handling system that discharges to one of the engineered biofilters to mitigate emissions. • Bulk density is managed to minimize emissions • Optimized C/N ratios are managed to minimize emissions. • Managing moisture levels in the composting mass (throughout the entire composting process) is an operational strategy used to enhance microbial activity minimizing emissions. • CASP: Composting occurs because of microorganisms. The primary goal of commercial composting is enhancing the environment where these microorganisms exist so that the process occurs more quickly and efficiently. This includes creating a microbial population that reduces unwanted emissions as well. Some of the conditions that enhance this process are supplying adequate aeration and moisture to the pile and insulating the composting mass. Our CASP system provides all of these functions which in turn reduce less desirable emissions (VOC, TAPs, HAPs). In addition, the CASP provides continuous monitoring to help operators maximize performance of the system. • A bio-layer of 12" of finished compost is used on top of each CASP batch to mitigate emissions. • An optimized engineered biofilter is used to mitigate emissions from negative process air and the tipping building. • Operation and maintenance of biofilter is important (more detail in Appendix B).

6	• Covering with compost overs (only for 3 days as an insulating cover to meet temp requirements for PRFP) • Completely enclosed building with air run through biofilter • Air supply for the building, over 170,000 cfm, is drawn from the receiving area that provides capture of the receiving area air • Maintaining oxygen levels above 13% throughout the process (oxygen levels maintained through management of bulk density and aeration) • Maintaining moisture levels between 45% and 55% • Management of bulk density
7	• Covering with compost overs • Cover feedstock mixture with 1 foot screened overs prior to primary aeration. • Use of biofilter • Maintaining oxygen levels at the appropriate level by maintaining pore space through appropriate feedstock mix • Maintaining moisture levels between 55% and 65% • Management of bulk density through feedstock mix and handling between stages
8	• 12" of finished compost are used on top of processing piles • Operators try to keep loose materials integrated into pile to help with emissions and odors • Use of biofilter
10	• Use of Gore Covers • Use of biofilter • Receiving area enclosure • Operations limit turning due to aeration • Management of bulk density
11	• Use of Gore Covers • Use of biofilter • Receiving area enclosure • 12" of compost overs are used in Phase 1 of Negative Air System • Operations limit turning due to aeration • Management of bulk density

Biofilter

If negative aeration is used, is it run through a biofilter? If yes, describe the biofilter. What type of biofilter maintenance is performed? How frequently is it replaced and how is it determined when replacement is needed?

Are there other areas in the facility where air is captured and run through the biofilter (e.g., tipping area)?

Table 16: Biofilter and air capture information, all facilities.

Facility	Biofilter information	Other air capture
1	2 aeration pads feed into separate biofilters – plan to replace every 2 years (still new)	N/A
2	N/A	N/A
3	N/A	N/A
4	Replace biofilters every 2-3 years depending on health of them, test quarterly for back pressure	N/A
5	2 biofilters - 4 aerated bays going to one biofilter, 4 aerated bays and air from tipping area goes to another biofilter (more detail on biofilters in Appendix B)	Tipping area
6	2-3 year replacement schedule; The main biofilters are designed to treat 172,000 cubic feet per minute of odorous building exhaust. Exhaust from the blowers is drawn through a 38-inch air duct, and vented to a 60-inch manifold, and through 10-inch sparger pipes. Specific design criteria for the biofilter are: Media Depth 5 feet when constructed. Loading Rate 5 Cubic feet per minute per square foot, Media Material 80 % wood chips and 20 % hog fuel overs, Moisture Content 50% to 65% (58% is optimum)	Captures air from entire 3 acre enclosed building
7	The 20 zone fan group utilizes two biofilters with footprints of 3,162 ft^2 each, which can scrub 18,000 cfm of exhaust air plus a matching amount of ambient air, or “cooling air.”	N/A
8	air is exhausted through a 36' x 60'X 4' bio-filter. The biofilter is made with wood chips and composted materials, watered and monitored. The system will only be switched to positive aeration for short durations if temperature or moisture corrections are required. Biofilter is replaced every 2 years, they haven’t had to add water to achieve the desired moisture.	N/A
10	Biofilters are only used at the receiving/grinding building where feedstocks are received, blended and shredded for composting in the Gore Cover Composting System.	N/A
11	Biofilters are used at the receiving/grinding building where feedstocks are received, blended and shredded for composting. Biofilters are used in all 3 phases of composting in the Negative Air System.	N/A

Summary

This report provides initial information on the variability of feedstocks, processes, and mitigation strategies used by 11 compost facilities, including the 10 largest compost facilities in Washington State (by amount of material processed). Facility 8 has significantly lower feedstock material amount but was of interest because WSU researchers will be using it as a field site for methodology development. At the time this report was submitted, only Facility 9 had declined to participate in the survey. Though the document review included documents from Ecology such as annual reports and permits, often there was limited detail included in these documents regarding the biofilter, so what was included was the information volunteered by the representatives of each compost facility.

The facilities surveyed in this project vary in terms of feedstocks and composting systems. Answers to several of the survey questions are summarized below. Study authors have not summarized process parameters, as those are best assessed in the context of the composting process at each individual facility. As with any such study, the level of detail provided in response to each question varies depending on the person providing the response.

Facilities with a large percentage of yard waste or mixed food/yard waste reported seasonal variation with an influx of grass during March or April through June and an influx of grass and leaves in the fall. Seasonal variation in some other feedstocks exists – composters in this survey mentioned agricultural waste products (e.g., cherries, pears, apples, grape pomace, pumpkins) as sources of seasonal variation. One facility mentioned moisture as being significantly different by season. Facilities have strategies for adjusting feedstock mixes (e.g., incorporating more woody materials during the spring when there are increases in nitrogen rich high-moisture feedstocks such as grass) to compensate for these seasonal changes.

Nine of the ten facilities that participated in this survey have mechanical forced air flow aeration systems (run on positive, negative or reversing). Two facilities have aeration systems designed by Green Mountain Technology. Five facilities have systems designed by Engineered Compost Systems. Two facilities have systems designed by Jumelet Environmental Engineering (with involvement of the compost company). The aeration systems include those that run only on as positive, only as negative, or as reversing. Sometimes different phases of the composting process vary in the aeration that is practiced. Appendix F illustrates as a graphical summary the facility processes used.

Eight of the ten facilities surveyed have a biofilter. Two facilities utilize Gore covers. Some compost facilities cover with overs (4 facilities) or with finished compost (2 facilities) (though exactly where in the process this covering occurs varies by facility).

Determining VOC emissions from facilities that use negative aeration will be an important component of any proposed Washington State VOC emissions study. Determining emissions form a negative aeration process will likely require a different air sampling method in addition to using surface flux isolation chambers. A schematic of a negative aeration system is shown in Figure 1. Our understanding is that the VOC concentrations in the process air stream *prior to being vented through the biofilter* is what has to be measured to derive a VOC emissions factor for the facility. For a negative aeration system, the VOC concentration in the duct ($\mu g / m^3$) and the air flow rate through the duct (m^3 / hour) would have to be determined. Most of the VOC emissions might be in this air flow rather than emitted in a diffusive process from the top of the pile. The pile emission rate (µg / hour) through the ducting would be calculated from the product of the measured concentration and the air flow rate. Measuring the concentrations in the duct air flow captures emissions from the entire pile. Determining the pile emission rate over the active phase of composting (15-30 days) would allow a VOC emissions factor to be derived from the initial pile mass (mass VOC emitted / wet ton compost). Emissions from the biofilter surface would also have to be measured. This could be done with surface flux isolation chambers.

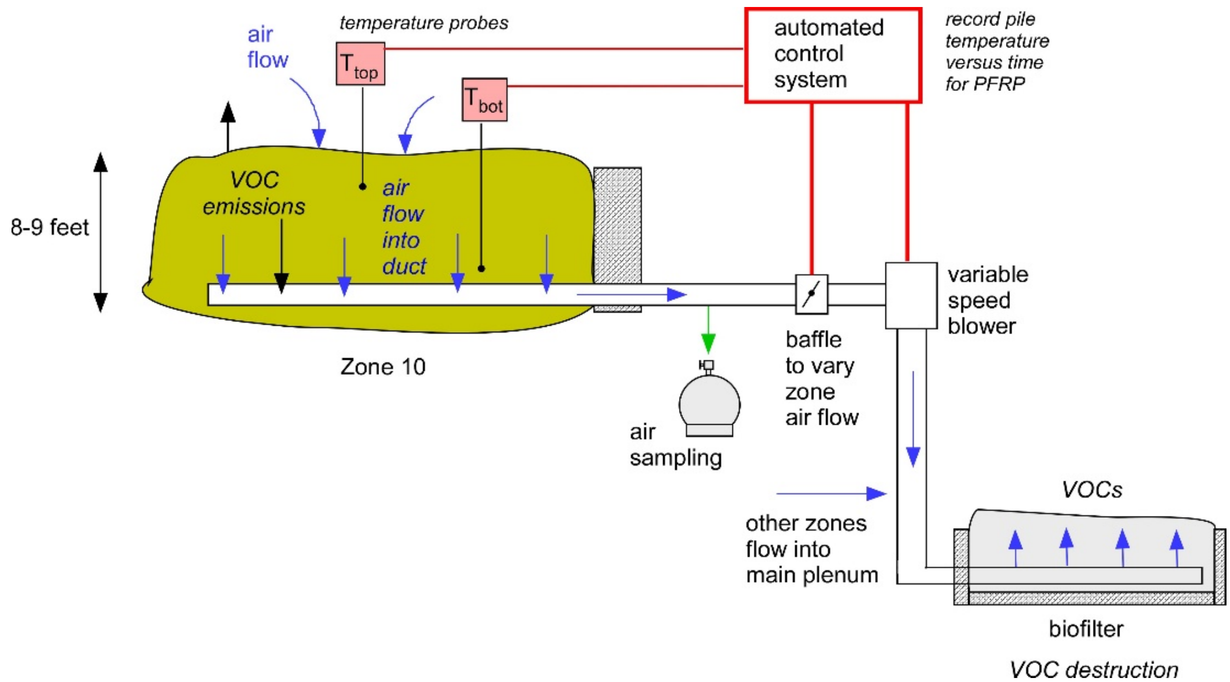

Figure 1: General air flow schematic for a negative aeration compost system. Air pulled through the pile sweeps VOC emissions into the ducting system where the airflow from multiple composting zones is combined and forced through a biofilter to remove emitted VOCs.

For positive aeration systems, a surface flux isolation chamber placed on top of the pile will in principle work as air is being forced through the pile to the surface and the resulting flux is captured by the chamber. In this case potential problems with using a surface flux isolation chamber will include a large water vapor flux coming from hot piles which can lead to condensation accumulating in the chamber and the resulting removal of water-soluble gases. The large size of the piles also warrants using surface flux isolation chambers with a much larger surface area than was used in the Department of Ecology compost facility emissions survey conducted between 2010 and 2013. A representative sampling of the surface flux is an issue if the flux isolation chamber only measures from a very small fraction of the pile's surface area. The flux isolation chamber used in the survey measured emissions from a ~ 1.5 ft^2 surface area, compared to a typical pile's 1000 ft^2 ridge surface area. This issue may be more important with positive aeration systems compared to passive windrows, because forced air flow through the pile may not be uniform depending on the underlying porosity, leading to large spatial variations in surface fluxes.

Most of the facilities using mechanical aeration also turned the piles. When turning VOC emissions will occur as the pile is ventilated. The amount of VOCs emitted will be difficult to measure unless the pile is within an enclosed building.

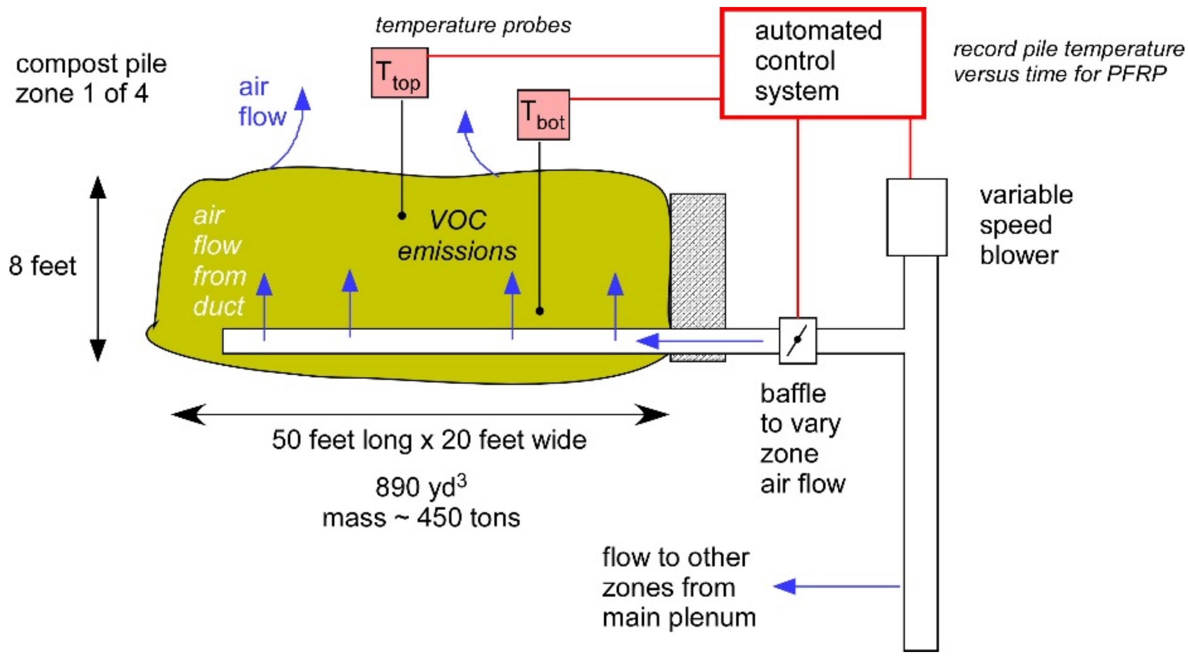

Figure 2: General schematic of a positive aeration system. VOC emission rates would be determined using flux isolation chambers on top of the pile.

A couple of facilities used a covered pile system. In these cases, the pile is covered by a polytetrafluorethylene fabric (W.L. Gore and Associates). The fabric is permeable to gases. In these systems air is supplied to the pile with positive aeration. Air flow carrying VOC emissions either passes through the fabric or around the fabric cover if it is not well sealed around the edges. A surface flux isolation chamber at the top of the pile would work to measure emissions emitted from the top of the pile. It would be more difficult to measure emissions from any air leakage around the edges of the cover. Such a system might be difficult to evaluate because of potential uncertainties in determining where the air flow is going (through the cover or underneath the cover).

Appendix A: Survey Questions

Feedstock Mix

Please verify the annual feedstocks shown in the attached 2017 spreadsheet (from Ecology) and describe how much variability exists in the composition of these feedstocks by month (composition and relative quantity).

Please describe mixing process – what defines a good mix and how is mixing performed?

What is the typical range of density (lb/cy), C:N ratio, and percent moisture of the initial feedstock mix that the facility encounters throughout the year?

Is there a time of year that you think the feedstocks vary enough that it could affect emission rates significantly?

Process

Please describe the composting process(es) used at your facility, in terms of type of system, size of piles, aeration- forced (negative and/or positive and air throughput) or passive, and pile temperature. When there are separate systems, please describe each separately and estimate the percentage of total material at the facility that is run through each process.

Please describe the process at each stage (for example, active composting, compost stabilization, curing) using the table below. If there is a portion of your waste stream which is kept entirely separate and run through a different set of processes, please describe that separately.

Please list typical values for these key process indicators at different stages of the composting process.

	Active Composting	Stabilization	Curing
Typical length of process (days)			
Average High Temp			
Average Temp			
Average % Oxygen			
Average pH			
Average Pile Depth			
Average Aeration Rate (cfm/cy)			
Aeration Mode (positive, negative, reversing)			

What type of aeration system do you have (and which company designed it)? For systems that are set up for both negative and positive aeration, what are the parameters that determine whether negative or positive aeration is used? What percentage of time (estimated) is positive aeration used in these systems and how does this vary by season?

Emission Mitigation Strategies

Please describe any emission mitigation strategies that are used in the composting process, for example:

- use of Gore Covers
- covering with compost overs
- use of biofilters (see question below)
- receiving area enclosure (see question below)
- maintaining oxygen levels above 13% throughout the process
- maintaining moisture levels between 45% and 55%
- reducing turning if aerated, or increasing turning if not aerated
- management of bulk density

Biofilter

If negative aeration is used, is it run through a biofilter? If yes, describe the biofilter. What type of biofilter maintenance is performed? How frequently is it replaced and how is it determined when replacement is needed?

Are there other areas in the facility where air is captured and run through the biofilter (e.g., tipping area)?

Is there anything else you'd like to tell us about your operation that is relevant to this topic?

Appendix B: Additional Detail from Facility 5 Survey Response

Facility 5 provided very detailed written responses to survey questions. The additional detail not provided in the main body of the report is shown below.

Feedstocks

Facility 5 receives the bulk of their feedstocks from urban curbside recycling. Comparing these feedstock compositions and quantities by month is not relative (a month is an arbitrary time-period not based on the varying conditions of feedstock generation). However seasonal variations are relative because feedstock quantity and character can change over these timeframes. We will therefore answer this question based on the more relevant seasonal variabilities.

The composition of our feedstocks is relatively stable but do exhibit seasonal characteristic and quantity variability due to cultural and environmental factors.

Nitrogen-rich vegetative feedstocks in the spring and fall (such as grass clippings in the spring, pumpkins in the fall) can occur for relatively short periods of time in quantities sufficient to warrant changes to feedstock processing. Culturally-related variations such as pumpkins persist for approximately a week while other vegetative variations such as grass clippings can occur for longer periods of time and are more dependent upon seasonal environmental conditions than the cultural influences from which they originate.

Quantity at Facility 5 is tracked in tons of material received. Incoming tonnage variability is primarily influenced by feedstock generator volumes and moisture content of the feedstocks. Incoming tonnage variability is primarily controlled through contractual agreements and functional capacity at our site.

During years with significant precipitation and extended dry periods, moisture can be a significant factor in seasonal variations because vegetative material moisture content varies due to these environmental conditions. Seasonal quantitative variabilities at the Facility 5 site can increase feedstock availability up to 30% in the spring and fall during years with significant precipitation and extended dry periods if not controlled through contractual arrangements. During years without these environmental conditions feedstock availability varies as little as 10%.

However, these variables have little influence on annual emissions generated from the composting process if proper operating procedures are followed (see mixing process below) and because the duration of these events occurs over a relatively short timeframe. Nitrogen-rich high-moisture feedstocks such as grass are balanced in the feedstock mix by incorporating more woody materials. High carbon sources are balanced by adding nitrogen-rich feedstocks. Our CASP system reaches thermophilic temperatures quickly so moisture is further balanced in a relatively short time frame through the evaporative process as needed.

Please describe mixing process – what defines a good mix and how is mixing performed?

A good mix starts with sourcing nitrogen-rich and carbon-rich feedstocks in adequate quantities. This is part of our site management strategy that begins with identifying appropriate sources and contractual conditions. Green landscape waste, food wastes, animal manure and other byproducts are relatively high in nitrogen and moisture content. Carbon-rich materials such as land clearing debris, compost overs and wood chips are commonly used as "bulking agents" to provide porosity and energy for composting. They are also used to balance moisture content if the organic feedstock is excessively moist. Woody materials such as compost overs and wood chips are the most common bulking agents, since they have the structural rigidity required to maintain porosity for adequate airflow. In general, fresh green wood chips have more energy than older recycled chips. Particle size also determines the available energy in the mix. Sawdust, for example, will generate more heat than chips.

After appropriate quantities of nitrogen and carbon are acquired, an adequate mix is further defined by the trained compost operator using observable characteristics. Particle size and moisture are the next key factors in building a good compost mix. Other factors such as pH have already been verified during initial testing of feedstocks prior to acceptance at the site or are well known. In our system a good mix is verified by a quick temperature rise in the CASP indicating microbial activity has begun. Experience with different types of feedstocks, particles sizes, and moisture content provide the trained compost operator with the skills to develop theses mixes. Direct experience with this process is crucial to preparing a good compost mix.

What is the typical range of density (lb/cy), C:N ratio, and percent moisture of the initial feedstock mix that the facility encounters throughout the year?

Pile Porosity (Density)

In order to provide rapid aerobic composting, the feedstock must be adequately shredded or ground to increase the surface area available for degradation by microbes. Feedstock mixes for our CASP system have an approximate 30% free air space in order to maintain optimum aerobic conditions and to create sufficient surface area for microbial activity. This feedstock will typically have an approximate bulk density of 950 pounds per cubic yard if all other factors are in normal range.

Volatile Solids and Carbon/Nitrogen Ratio

Adjusting the ratio of the nitrogen-rich feedstock to the carbon-rich bulking agent controls the carbon/nitrogen (C/N) ratio of the compost mix. The desired C/N ratio is between 20:1 and 40:1.

Moisture

The target moisture content of the initial composting mix is 40-60%. Optimal moisture levels for composting occur when materials are about as moist as a wrung-out sponge. They should be obviously moist to touch but yield little liquid when squeezed.

Please describe the process at each stage (for example, active composting, compost stabilization, curing) using the table below. If there is a portion of your waste stream which is kept entirely separate and run through a different set of processes, please describe that separately.

Active composting: Washington State has not defined the term Active Composting in law or rule. Many research projects use the term "active composting phase" but do not define the condition well. California has a definition in their rules (e.g. CARB Rule 4566) that states the following:

3.1 Active Composting: the phase of the composting process that begins when organic materials are mixed together for composting and lasts until one of the following conditions is met:

3.1.1 The organic material emits no more than seven (7) mg carbon dioxide per gram of organic material (CO_2-C) per day, as measured using the test method in Section 6.2.1.1; or

3.1.2 The material has a Solvita Maturity Index of 5 or greater as measured using the test method in Section 6.2.1.2; or

3.1.3 The material has been composted for a period of at least 22 consecutive calendar days.

Unfortunately the CARB definition does not consider some key points of the composting process and fails to incorporate the variables of technology. The beginning of the process should not be defined by pile formation alone. Only pre-cursors to the composting process are occurring at this time. Until there is evidence of a stable microbial population active composting is not occurring. The rule then uses one of three methods to show cessation of the process. The first relies on CO_2 emissions, the second on the Solvita test (measuring NH_3 and CO_2), and the third is an arbitrary duration of time. Both of the emission testing methods have been shown to be highly variable; especially when attempting to assess early stages of compost stability (Reference "Determining the Most Effective Method of Measuring Compost Maturity"; Flemming et. al. and others). A set time period for active composting also fails to account for the many variables that exist in the process. For this analysis we will use the following definitions.

- Active Composting: After feedstock preparation and initial compost pile formation, active composting begins when operators create an aerobic environment in the compost, begin to actively manage the composting mass, and temperatures indicate mesophilic organisms have begun to form in substantial quantities. For our system a stable temperature increase of at least five degrees Celsius above ambient for twelve hours is used to show microbial activity is wide-spread throughout the pile. Mesophilic organisms in the compost are quickly replaced by thermophilic organisms. This thermophilic activity may last from 3 – 20 days depending on pile composition and operational inputs. During the thermophilic phase of composting, microorganisms and high temperatures accelerate the breakdown of organic compounds in vegetation and food. As the supply of these "high-energy" compounds is depleted the activity level of the pile, characterized by output emissions and input requirements for air and moisture, stabilize and subside. The subsidence of active composting is verified by the trained compost operator through an evaluation of the composting mass using visual and olfactory senses, as well as emission measurements and other testing as necessary.
- Stabilization: As with active composting, the term "stabilization" of compost is a widely used term without a generally recognized definition. At our site stabilization begins after a majority of the above described "high-energy" compounds have been depleted from the composting mass and the active composting stage ends. This stage is characterized by lower input requirements of air and moisture to maintain the composting process and lower overall emissions. The composting material is visually altered from the active phase and exhibits a more stable, less offensive (to humans) hedonic tone and fewer overall emissions.

- Curing: At the Facility 5 site curing occurs after the compost has met all regulatory requirements of final compost (WAC 173-350-220) and is characterized by mesophilic temperatures, low odor emissions, and low input requirements.

What type of aeration system do you have (and which company designed it)? For systems that are set up for both negative and positive aeration, what are the parameters that determine whether negative or positive aeration is used? What percentage of time (estimated) is positive aeration used in these systems and how does this vary by season?

Phase I composting at our site uses a Covered Aerated Static Pile (CASP) system designed by Engineered Composting Systems (ECS) of Seattle WA. The system was designed to incorporate the flexibility of positive, negative, reversing and quiescent durations of aeration. We have traditionally used a reversing aeration regime as its primary composting process. However, we have used positive only, negative only, and various combinations of these processes, combined with quiescent periods, all with acceptable results. Whether operated in positive only, negative only, or reversing, the system is typically active from 30% to 60% of the time with the remaining operating time being quiescent. During the wet season active aeration is often near its maximum.

Phase II composting at the Facility 5 site uses windrow composting designed by [Name of composter]. Aeration of the pile is both passive and active. Active aeration occurs when the windrow is mechanically turned and exposed to ambient air and occurs approximately every seven days. Passive aeration occurs continuously because of several conditions. The size and geometry of the windrow are designed to allow oxygen to flow throughout the pile while maintaining temperatures in the proper range. During static periods temperature gradients and convection pull ambient air into the pile and exhaust it primarily through the top. Mechanical aeration in this case occurs from all angles whereas passive aeration occurs primarily in the positive direction.

During Phase III composting (curing) at the site, the mechanism for aeration is similar to Phase II composting except that pile geometry is different and pile tuning occurs less frequently.

Please describe any emission mitigation strategies that are used in the composting process. (Additional detail for response provided in report)

Operation and maintenance are critical to a well-performing biofilter or composting biomass. Sufficient water content is one of the most important parameters for effective biofiltration of emissions because microorganisms responsible for the degradation of odorous compounds and other emissions require adequate water to perform their normal metabolic reactions. In addition, appropriate moisture content is required for gas-water phase transition and movement of odorous molecules into the biofilm. Facility 5 biofilters are moisturized as needed. Enough moisture is applied to the biofilters to saturate the top of the biofilter which is a common industry standard (i.e. “Bioreactors for treatment of VOCs and odors - A review” Mudliar et al., 2014; and “Biofiltration of Volatile Organic Compounds (VOCs) – An Overview” Thakur Prabhat Kumar et. al. 2015). The documents “San Joaquin Valley Unified Air Pollution Control District Final Draft Staff Report, and the subsequently published Rule 4566, describe the use of watering for emissions reduction on any composting mass to mitigate undesirable emissions. Our facility uses moisture in this way to control emissions from the biofilter, the CASP, the windrows and curing piles. An emission control value of 19 percent is given as a reduction in the 4566 Rule. Actual site emission measurements indicate this is a conservative estimate of emission reduction using this technique.

Emissions at composting facilities are also generated from the use of fossil fuels and electricity use. While these emissions are apparently not within the scope of this analysis, it should be noted that we employ several strategies to minimize this emission.

Biofilter

If negative aeration is used, is it run through a biofilter? If yes, describe the biofilter. What type of biofilter maintenance is performed? How frequently is it replaced and how is it determined when replacement is needed?

Are there other areas in the facility where air is captured and run through the biofilter (e.g., tipping area)?

When negative aeration is used at the site it is exhausted through an engineered biofilter prior to release. Tipping building air is also captured and exhausted through the biofilter.

Biofilter maintenance occurs daily. Internal temperature and moisture are checked and adjusted as needed to optimize performance. Surficial moisture is checked and adjusted daily to aide in emission control. Biofilter flow is checked monthly by site operators to ensure even flow across the surface of the biofilter is occurring. Issues are corrected immediately. Third-party biofilter review and maintenance occurs annually. An extensive review of biofilter performance is conducted during this annual review and issues are corrected immediately. Biofilter replacement occurs either when a structural issue has manifested (i.e., channeling or excessive back pressure is measured in the system, etc.) or approximately every three years.

The biofilter has been designed to incorporate the following specifications:

Residence time	40 – 90 seconds
Media temperature	10° – 50° C
Active media depth	36” – 66”
Media components	95 - 97% screened coarse resilient wood (ideally shredded root wood) chips sized 1” to 2” plus (discard the fines) 3-5% stable compost
Media moisture content	>50%
Max pressure drop through media	< 0.5” SP/foot of depth (once greater than this the media should be replaced)

Is there anything else you’d like to tell us about your operation that is relevant to this topic?

During this exercise we have assumed “emissions” to mean regulated emissions from composting facilities. Some answers may be different if the intent is to encompass all emissions.

Some of the examples of emission mitigation strategies listed are not stand-alone mitigation techniques (e.g., do not work without the control of several other factors) or have not been proven to reduce emissions.

- **Receiving area enclosure (see question below)** – An enclosed receiving area is not a stand-alone emission mitigation strategy without supporting emissions treatment.
- **Maintaining oxygen levels above 13% throughout the process –** Excess oxygen can in some cases increase unwanted emissions and be detrimental to the composting process.
- **Maintaining moisture levels between 45% and 55% -** This range is too restrictive and does not include other complimentary or detrimental factors that can affect how moisture affects emission generation.
- **Reducing turning if aerated, or increasing turning if not aerated management of bulk density** – Research and in-situ testing has shown that in some cases increased turning for passive systems can in fact increase undesirable emissions. Once again, this is not a stand-alone emissions mitigation strategy.

Appendix C: Annual Feedstock Variability for Facility 11

Monthly feedstock reports were obtained from the local health jurisdiction for Facility 11 for Oct 2018 – Oct 2019.

	yard debris (tons)	yard debris/foodwaste mixed (tons)	paper waste (tons)	foodwaste mixed (tons)	new bulking agent added to process (tons)	stumps, land clearing, branches (tons)	wood waste (tons)	reused bulking agent added to process (tons)	Monthly totals (columns B-F from pdf reports) (tons)
Oct-18	1,916	14,479	2	3,891	0	338	155	9,298	20,780
Nov-18	2,122	20,486	3	3,100	0	190	147	10,599	26,047
Dec-18	1,864	12,611	1	2,738	0	150	199	7,534	17,562
Jan-19	2,117	13,446	3	2,572	0	930	213	6,717	19,280
Feb-19	1,079	6,284	2	2,909	44	397	119	5,103	10,834
Mar-19	1,955	11,332	2	2,988	98	881	148	6,405	17,405
Apr-19	1,868	16,976	2	3,182	0	754	170	9,173	22,952
May-19	2,474	23,980	7	3,237	642	832	190	12,658	29,459
Jun-19	1,998	17,659	1	3,317	0	592	208	13,113	23,776
Jul-19	2,253	13,802	3	3,557	0	902	193	9,777	20,710
Aug-19	2,168	12,892	3	3,449	0	661	197	8,445	19,369
Sep-19	1,982	11,319	2	3,489	0	820	167	7,166	17,779
Oct-19	2,031	14,602	3	3,430	0	855	173	9,398	21,094

Appendix D: Additional Comment from Survey Respondent

This appendix captures an additional comment that fell outside of the survey questions but are relevant to the topic being covered.

One respondent wanted to make sure that whatever we do gets seen by Ecology Air Quality because he says that often there are interesting studies done by Ecology Solid Waste that are not seen/paid attention to by Ecology Air Quality or by the Clean Air Agencies. He also emphasized getting buy-in on the front end of studies by the regulators.

Appendix E: Definitions of Composting Terms

From USCC Training Guide (1997):

Active Compost: Means compostable material that has undergone the time/temperature Process to Further Reduce Pathogens (PFRP), and is undergoing or capable of undergoing rapid decomposition but isn't sufficiently stabilized for use as a soil amendment; not suitable for use as a composting inoculant because it may not be sufficiently advanced to contain a full spectrum of microorganisms; biological oxygen and nitrogen demanding and capable of generating heat; not horticulturally or agronomically beneficial in its present condition. Synonymous with "green compost."

Stabilization: The second stage of composting (following after the high-rate decomposition stage) that occurs after undergoing the Process to Further Reduce Pathogens (PFRP) as described in the US EPA 40 Code of Federal Regulation Part 503 Appendix B, item B. The stabilization stage is characterized by a slowing in metabolic processes, lower heat production, and the formation of humus. If kept properly moist and turned and aerated during the stabilization stage cellulose and hemicellulose will degrade and organic phytotoxins that may have formed during high rate decomposition will be reduced as further decomposition takes place. The stabilization stage is followed by the compost curing stage in compost production.

Curing: The last stage of the composting process that occurs after most of the readily metabolized material has been decomposed and stabilized. Curing eliminates organic plant phytotoxins, consumes fungal substrate, and provides additional biological stabilization, especially the decomposition of cellulose, hemicellulose and lignin, and provides maturity, and begins a prolonged period of humification and mineralization.

From Compost Facility Resource Handbook 85 November 5, 1998. Washington Department of Ecology:

Active composting: Compostable material that has undergone the time/temperature Process to Further Reduce Pathogen (PFRP) and is undergoing or capable of undergoing rapid decomposition but isn't sufficiently stabilized as a soil amendment; not horticulturally or agronomically beneficial in its present condition.

Curing: The last stage of the composting process that occurs after most of the readily metabolized material has been decomposed and stabilized.

Appendix F: Graphical Summary of Facility Processes

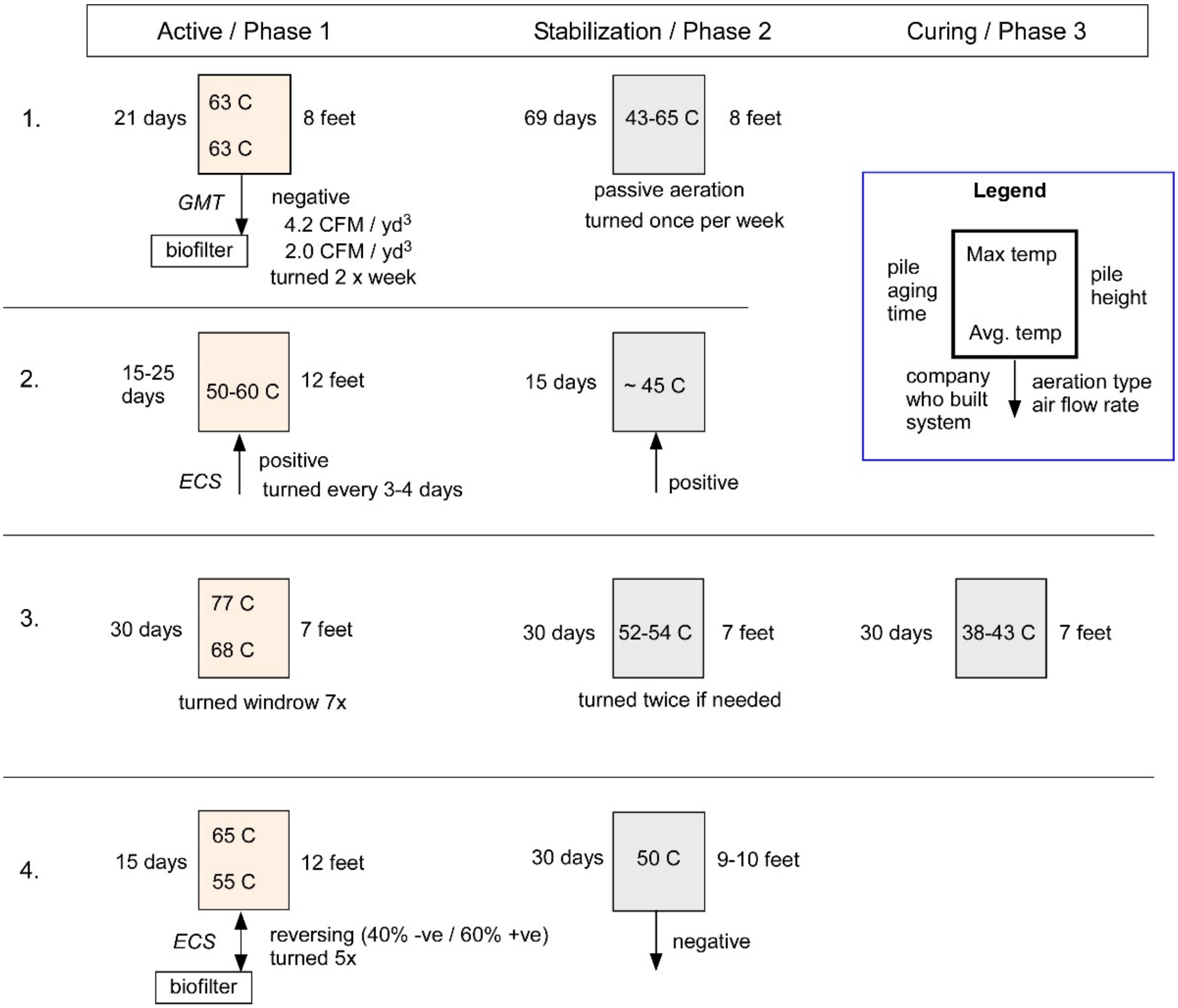

Figure F.1: Process summary for facilities 1 through 4, showing pile heights, pile aging times, pile temperatures, aeration process, and company who built the system (ECS = Engineered Compost Systems; GMT = Green Mountain Technology; JEE = Jumelet Environmental Engineering)

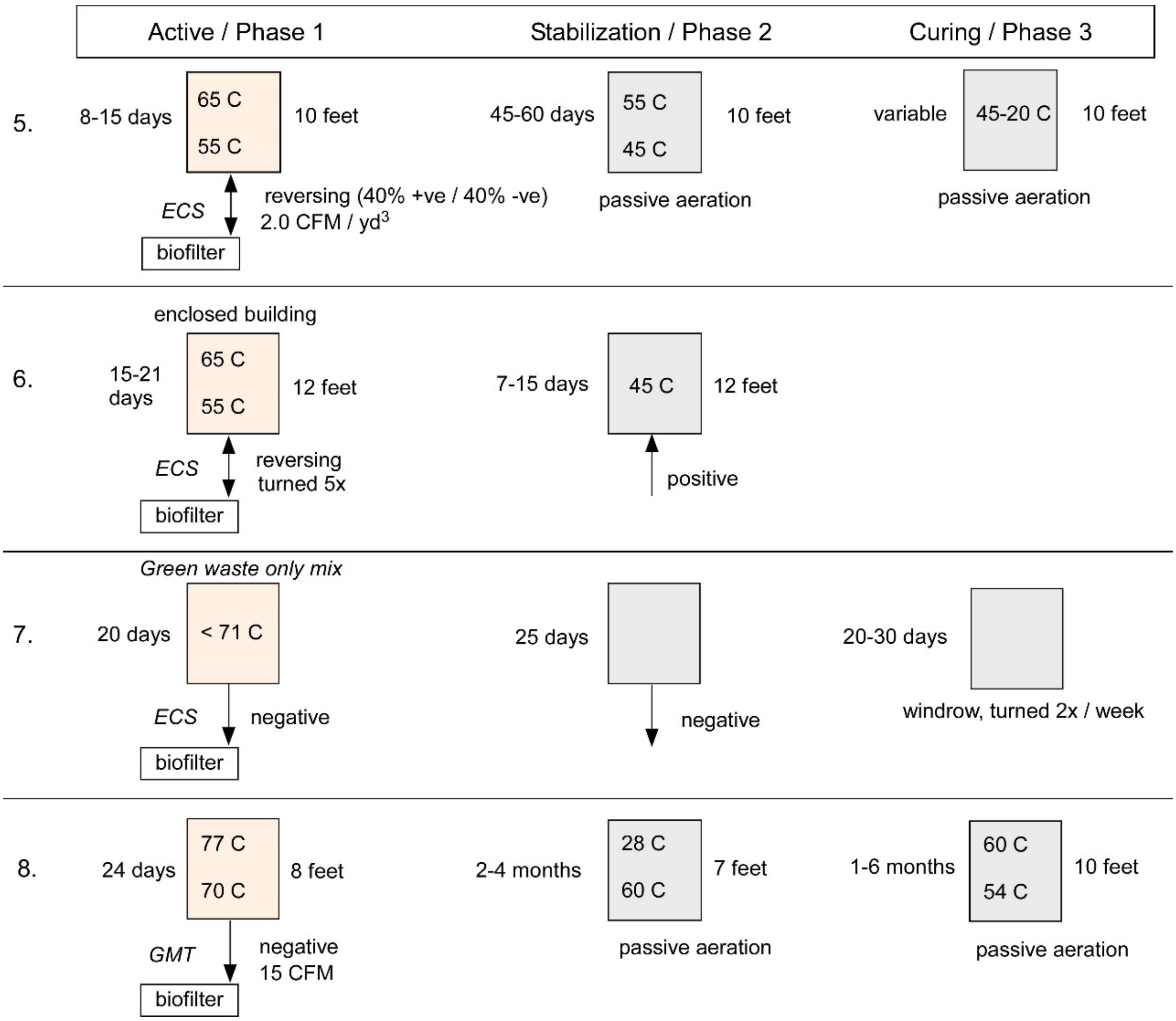

Figure F.2: Process summary for facilities 5 through 8, showing pile heights, pile aging times, pile temperatures, aeration process, and company who built the system (ECS = Engineered Compost Systems; GMT = Green Mountain Technology; JEE = Jumelet Environmental Engineering).

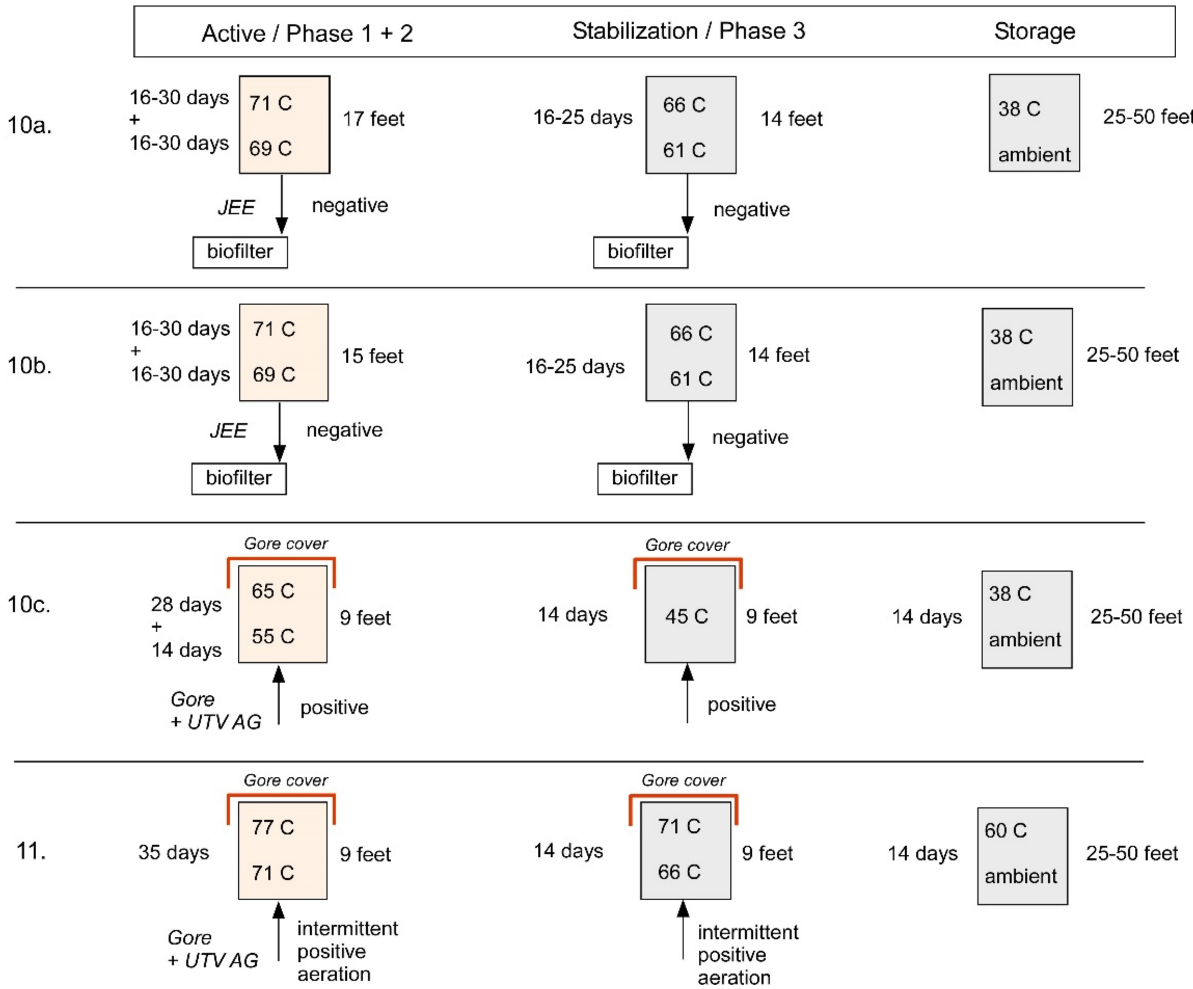

Figure F.3: Process summary for facilities 10 and 11. Facility 10 has 3 distinct processes on-site. Schematic illustrates pile heights, pile aging times, pile temperatures, aeration process, and company who built the system (ECS = Engineered Compost Systems; GMT = Green Mountain Technology; JEE = Jumelet Environmental Engineering; Gore = W.L. Gore and Associates Inc.; UTV AG (Germany).

Appendix G: Emissions Sampling Considerations

Based on this study, our other work to date, and the work of others, some recommendations can be made to help develop plans for a potential VOC emission factor study for Washington State composting facilities. We assume here that the greatest emission rates are from actively composting piles and that such a study would have its principal focus on sampling these emissions. These recommendations would require further refinement by both Ecology and other stakeholders in the air permitting process such as EPA Region 10. However, our goal in providing some initial suggestions is to aid Ecology and other partners in thinking about approaches, which could be further developed into a sampling plan.

The largest facilities in the state process green waste (yard debris) and food waste materials. The mix of materials changes somewhat by season for some facilities according to the data collected from the survey. Difference in feedstocks between spring (more grass clippings) and fall (more leaves) were noted. These seasonal differences might impact VOC emissions rates and the types of compounds released during composting. However, at least one facility operator stated that seasonal variation in inputs should not result in significant changes in emission rate changes if the same C/N ratios, moisture levels, porosity, and air flow are used throughout the year. Based on these findings, it seems warranted to pair summer sampling with spring or fall sampling to measure potential seasonal differences of emission rates and types of VOCs emitted.

Another major point highlighted in the survey is that there are different composting systems used across Washington. These different process types may well have different VOC emissions rates and different type of compounds emitted, all else being equal, because of differences in the composting process. The most notable difference between process types in the survey was between reversing aeration and Gore covered piles. An emissions study should probably consider sampling from the most common process types, if feasible, to better understand if one average emissions factor can be reasonably applied to all compost processing types. As a first cut, we suggest selecting 4 types of facilities for an emissions study: a turned windrow system, a negatively aerated pile system, a reversing system, and a Gore cover system. One representative facility from each type would be selected for sampling. For the turned windrow there was only one such facility. Table G.1 below lists which surveyed facilities were identified with each type of process. We suggest conducting two sampling tests at each facility (perhaps in different seasons) providing 8 VOC emission factor values in total for the study. This is perhaps enough to form a judgement about whether or not an average emissions factor can be reasonably used for all facility types. Sampling each facility twice allows the option of examining seasonal differences or simply examining the ability to get the same emission factor result for a repeated test. For a two-year study we would suggest sampling 2 facilities in each year.

Table G.1: Suggested sampling schedule.

Facility Type	Facility #	Year 1		Year 2	
		spring	summer	summer	fall
Turned window	3	x	x		
Negatively aerated pile	1, 7, 8, 10a, 10b	x	x		
Reversing aerated pile	4, 5, 6			x	x
Gore cover	10c, 11			x	x

Sampling facilities that utilize negative aeration present some special challenges that will need to be resolved. Note that as both negative and reversing aeration systems utilize negative aeration, this challenge applies to the majority of facilities in this survey. For negatively aerated piles, sampling the ducts containing the process emissions will be required, requiring a completely different sampling procedure than the surface flux isolation chamber sampling methodology used for windrows in previous California studies. These air flows are at elevated temperature and humidity and at sub-ambient pressures. Sampling from ducts may require making penetrations into facility equipment to provide access to the process air stream, and the willingness of facilities to make these penetrations would need to be explored. Sampling from negatively aerated piles would also require further deliberation with the EPA as to the best protocol and approved methods.

An alternative to sampling from commercial facilities that could be considered is to lease a pilot composting plant from a compost equipment supplier such as Green Mountain Technology (GMT) or Engineered Compost Systems (ECS). Such a pilot system would allow for testing different aeration configurations (positive, negative, reversing) at single site. Potential emission differences between aeration types using the same feed stock material could then be more easily quantified. The pilot plant would have to be located at a compost facility that could host and run the pilot plant and supply feedstock materials. The use of a pilot plant might get around potential problems of obtaining agreements from owners to have emissions sampling done on their facility, and potentially simplify the logistics and expense associated with traveling to different facilities across the state to conduct sampling. In addition, a pilot plant could be purpose built to allow for high quality sampling of negatively aerated process streams, achieving higher quality data than could be obtained at commercial facilities. This scheme would require the involvement of the equipment supplier and a facility operator to work. Having the various stakeholder's groups involved in the study as an advisory council (compost facility operators, air permit writers, equipment suppliers) would help define the most important issues concerning permitting and testing methods and provide a forum identify issues and disperse information.