Volatile Organic Compound Emission Factors from Green Waste / Food Waste Composting using the WSU Pilot Plant

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Project Purpose

1. Determine VOC emission rates from active phase of composting using a continuously aerated static pile system (CASP). *capability development*
    - Measure emission rates through negative aeration duct
    - Measure pile surface emission rates

2. Implement *SCAQMD Method 25.3* used in California for compost emission compliance testing and compare our results against a contract lab in California that supplies this service. *capability development*

3. Test utility of WSU pilot Plant for emission factor determination (lbs VOC / wet ton feedstock) *capability development*
    - WA needs emission factors for air permitting

Funded by EREF grant with Tim O'Neil (ECS, Seattle) and WA Dept Ecology Waste to Fuels Technology Program

4. Emission factor testing in 2023-2024 biennium for WA Department of Ecology ***Implement***
    - using US EPA approved emission test methods
    - Construct new pilot plant at WSU Puyallup

WSU Pilot Plant: Two Zone Aerated Static Pile System (Engineered Compost Systems)

Built at WSU Compost Yard

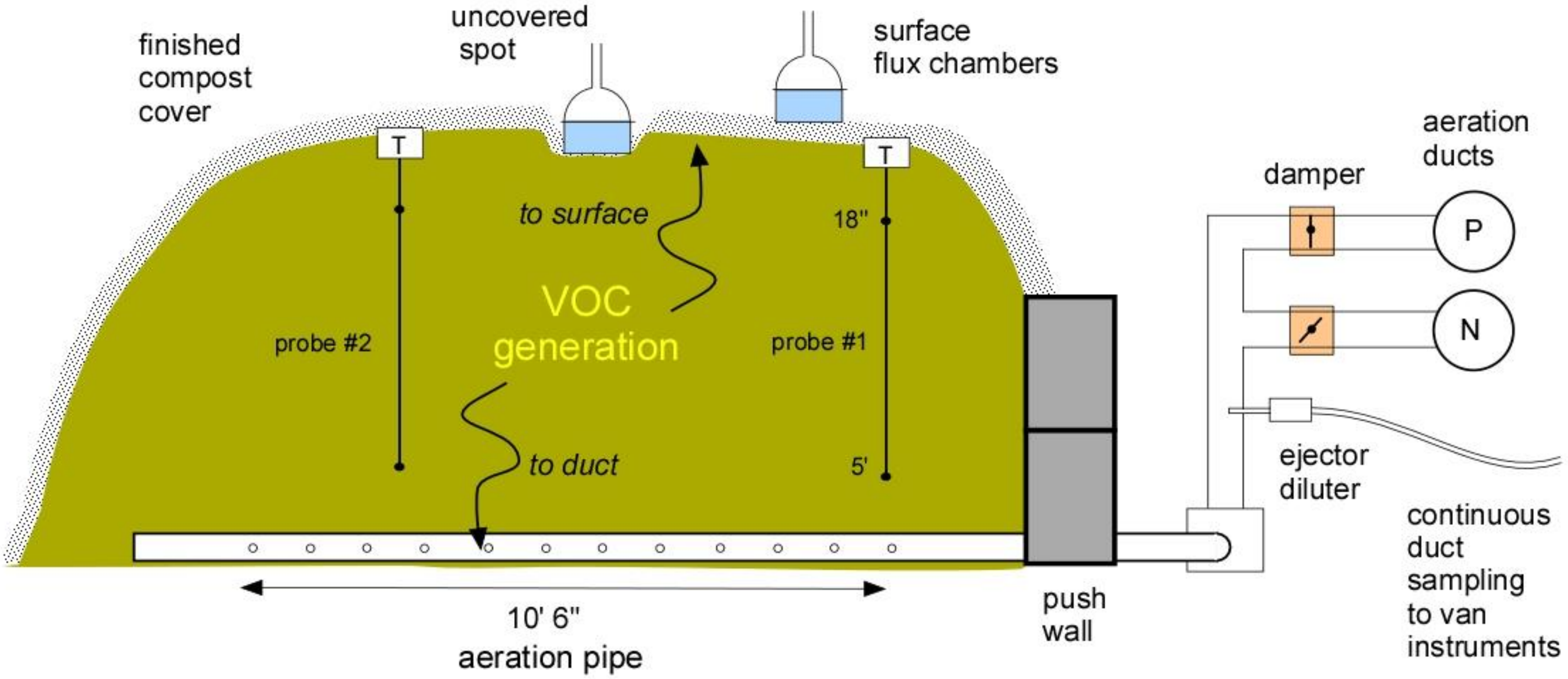
Piles built into two bunkers
6.5 to 7 feet high
12 feet wide
18 feet long
~45 CY

Bucket density tests done during mixing to get ~60% moisture. Bulk density ~960 lbs/CY.

Composite sample sent for analysis to Soil Test Farm Consultants for feed stock analysis test (C/N ratio, pH, total N, % moisture).

Zone Cross section Schematic

- Piles built into walled bunkers open at front end. Bunker walls 18 feet long, 12 feet apart, 4 feet high.
- Pile temperature monitored in 4 places with 2 probes.



VOC Emission Sampling

- **Continuous Negative Aeration Duct Sampling**
  data every minute

Custom built ejector diluter sampling from duct (~30 x dilution). Air sample sent to instrumented van.

VOCs by PTR-MS (30 compounds)

CO_2 & H_2O

CH_4 CO N_2O

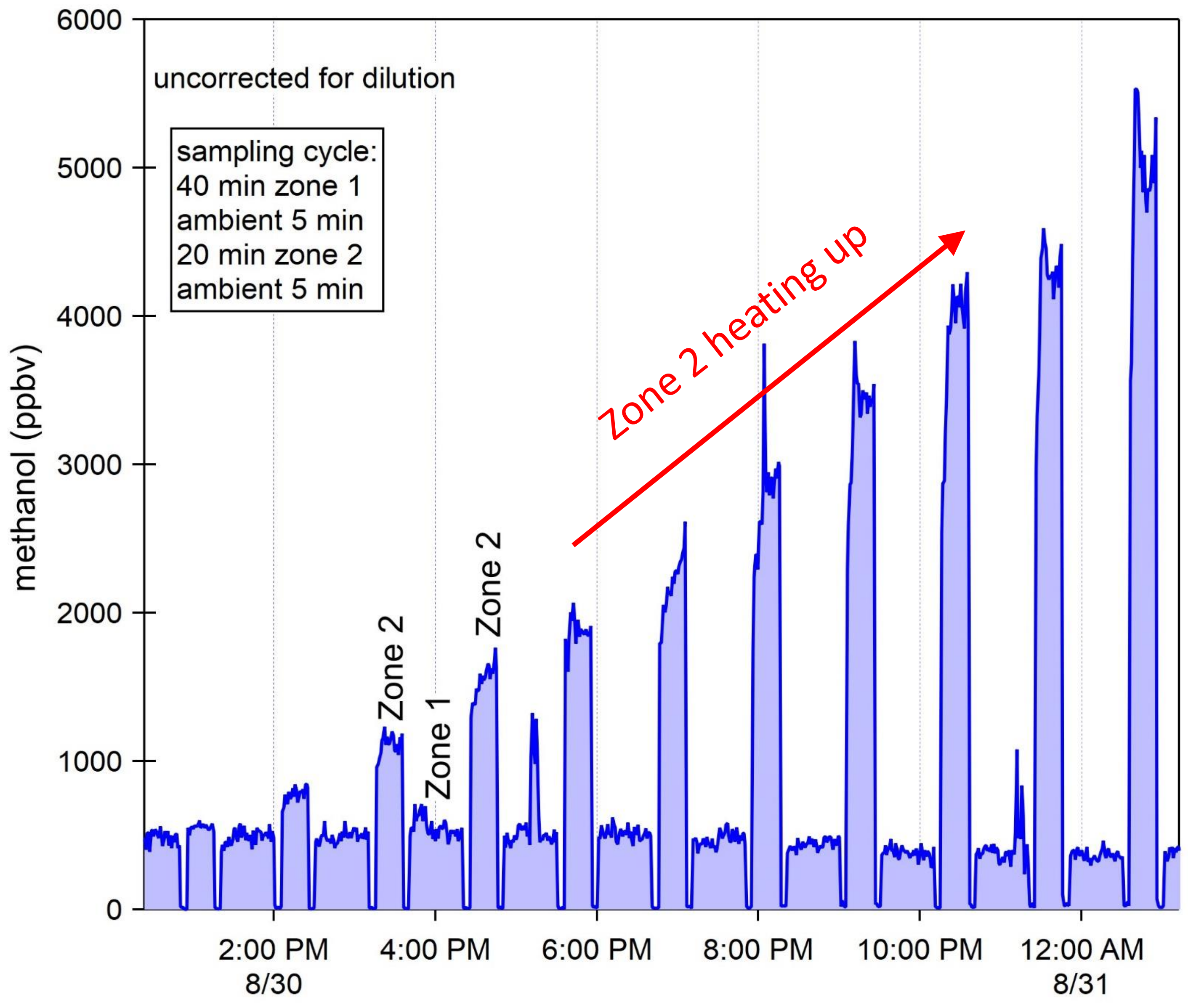
- **Surface flux sampling**

using flux chambers & Method 25.3 + GC-MS (EPA TO-15)

- **Sample directly from duct**

using Method 25.3 + GC-MS (EPA TO-15)

Continuous Negative Aeration Duct Sampling : Methanol data from **PTR-MS**



Example PTR-MS data (Run #3) showing automated switching of sampling between Zone 1 and Zone 2 negative aeration ducts.

Sample flow is diluted by a factor ~30 by clean VOC free zero air produced by a zero air generator in the van.

Emissions can rapidly increase in response to pile temperature changes.

Zone 1 : optimum air flow
Zone 2 : low air flow (want low O_2)

The innovation here is continuous sampling from the duct made possible using a heated ejector diluter.

Comparison Sampling with Method 25.3 sampling kit from WSU and Atmospheric Analysis & Consulting (AAC)

Side by side sampling from duct

Side by side sampling from flux chamber

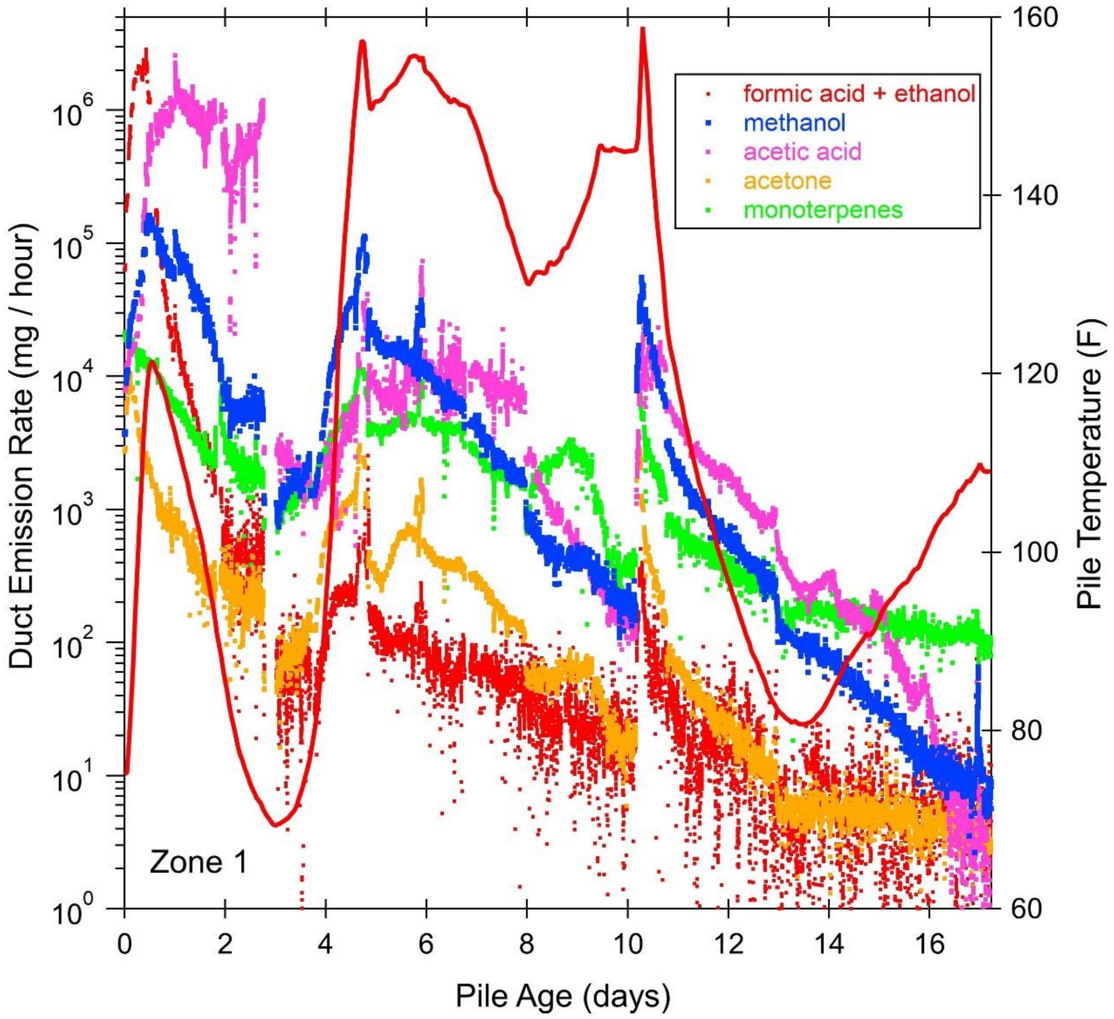
- Took > 1 hour to fill can, ~30 minutes to “stabilize” chamber.
- One person could do 4 samples per day given prep time and end of day clean up.

WSU Pilot Plant Run Information

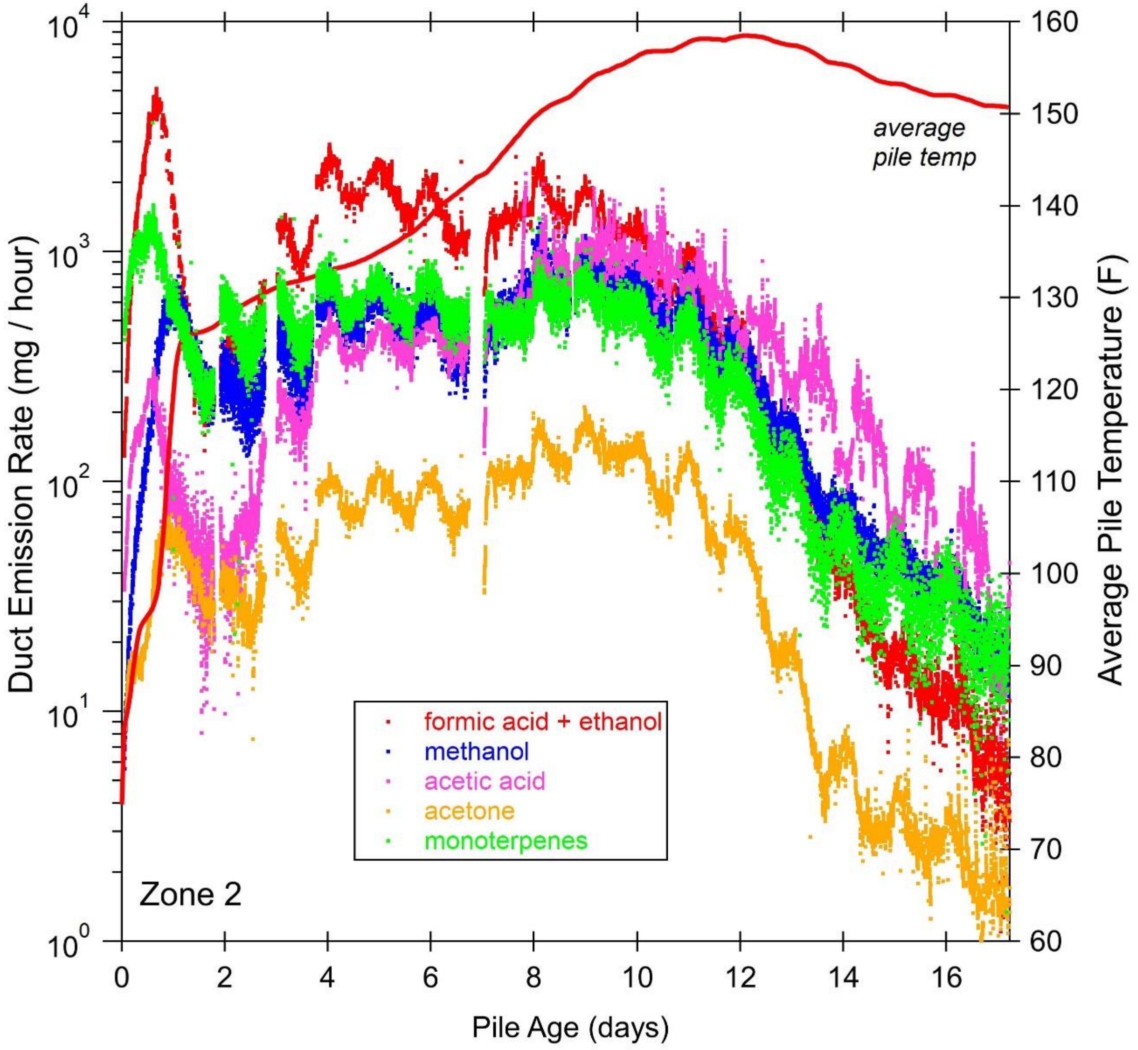
Run #	Pile Build Date	Zone 1	Zone 2	Zone 1 SCFM/CY	Zone 2 SCFM/CY	Z1 prs (" H2O)	Z2 prs (" H2O)	Feed Stock	Bulk Density (lbs/CY)	C:N ratio	pH	
R1	5/21/2022	neg	neg	3.5	1.5	-8 & -4	-8 & -4	ground yard waste (BarTech)	938	23	7.5	
R2	7/13/2022	neg	neg			-10	-10	ground yard waste (old WC)[1]	916	30	6.7	
R3	8/26/2022	neg	neg	4.5	0.28	-10	-10	26,00 lbs Organix food waste + new WC green[2] + 20 CY Ironsides[3]	938	24	4.7	
R4	9/20/2022	pos	neg	0.8	1.5	1.5 & 3	-6	18,300 lbs Organix + new WC green waste	978	28	5.1	
R5	10/17/2022	reversing	neg	4.2 & 1.0	4.2 & 1.0	-3 & +3	-3	14% Organix food waste (27,260 lbs) + 81% new WC green + %5 manure	1033	24	5.1	
R6	2/23/2023	pos	neg	1.5	1.2	3	-3	7% Organix food waste (13,000 lbs) + 88% new WC green + %5 manure. Mixer Broken. Mixed with windrow turner.	1129	20	7.0	wet mix
R7	4/7/2023	pos	neg	7.2 & 1.8	5.6 & 1.5	6	-6	25,000 lbs Organix Food waste + recently ground WSU green waste. Lost a lot of water from food waste so mix is dry.	767	22	7.2	dry mix

PTR-MS Sampling of Negative Aeration Duct (Run R3)

Zone 1: normal aeration 4.5 CFM / CY



Zone 2: constant low aeration 0.3 CFM / CY

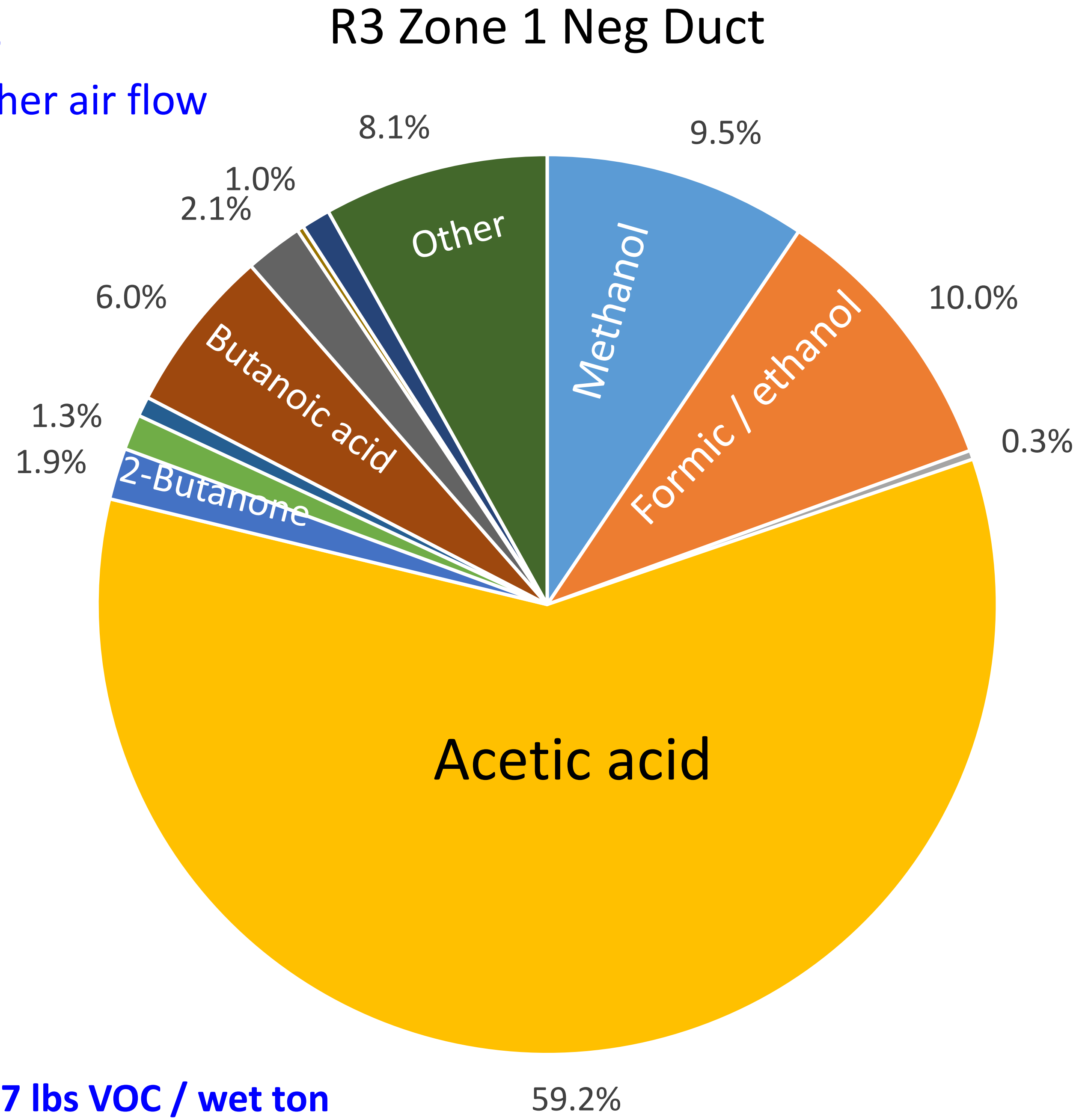


Organic acid emissions (**formic** and **acetic acid**) are a major emission

R3

Higher air flow

Mass Fraction of Total VOC Mass through Duct



1.47 lbs VOC / wet ton

Mass Compounds Emitted through Duct

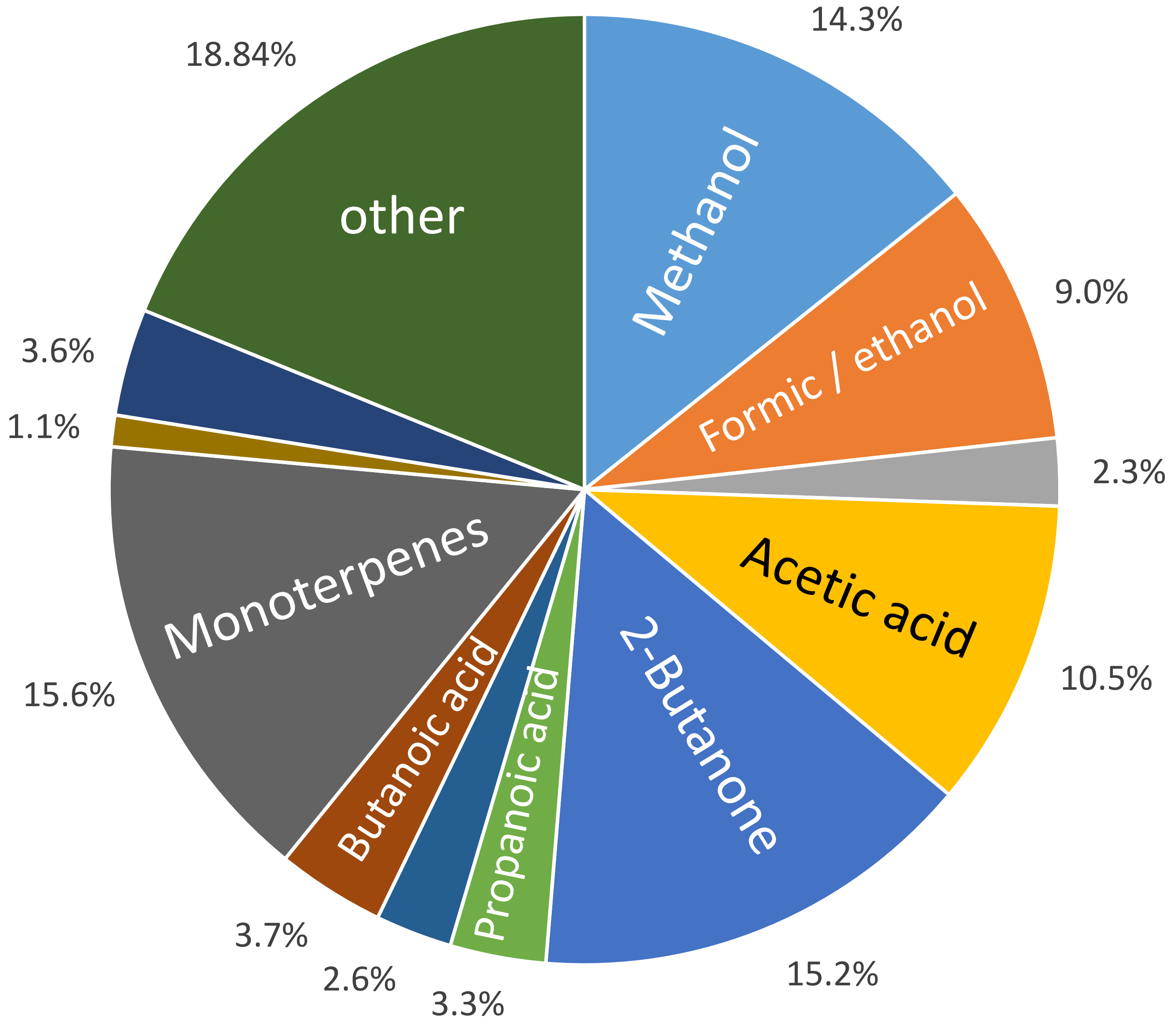
Compound	Formula	Actual lbs	Method 25.3 lbs as CH_4
Methanol	CH_4O	2.64	1.32
Formic acid /ethanol	CH_2O_2	2.79	0.97
Acetic acid	$C_2H_4O_2$	**16.5**	8.80
Propanoic acid	$C_3H_6O_2$	0.34	0.23
Butanoic acid	$C_4H_8O_2$	1.66	1.21
Acetone	C_3H_6O	0.09	0.07
2-butanone	C_4H_8O	0.52	0.46
pentanones	$C_4H_6O_2$	0.20	0.18
Monoterpenes	$C_{10}H_{16}$	0.58	0.68
$C_{10}H_{16}O$	$C_{10}H_{16}O$	0.07	0.07
Sesquiterpenes	$C_{15}H_{24}$	0.29	0.34
	Total	**25.7**	**9.3**
	lbs VOC / wet ton	**1.36**	**0.76**

R3

Lower air flow

R3 Zone 2 Neg Duct

Mass Fraction Emitted of Total VOC Mass through Duct



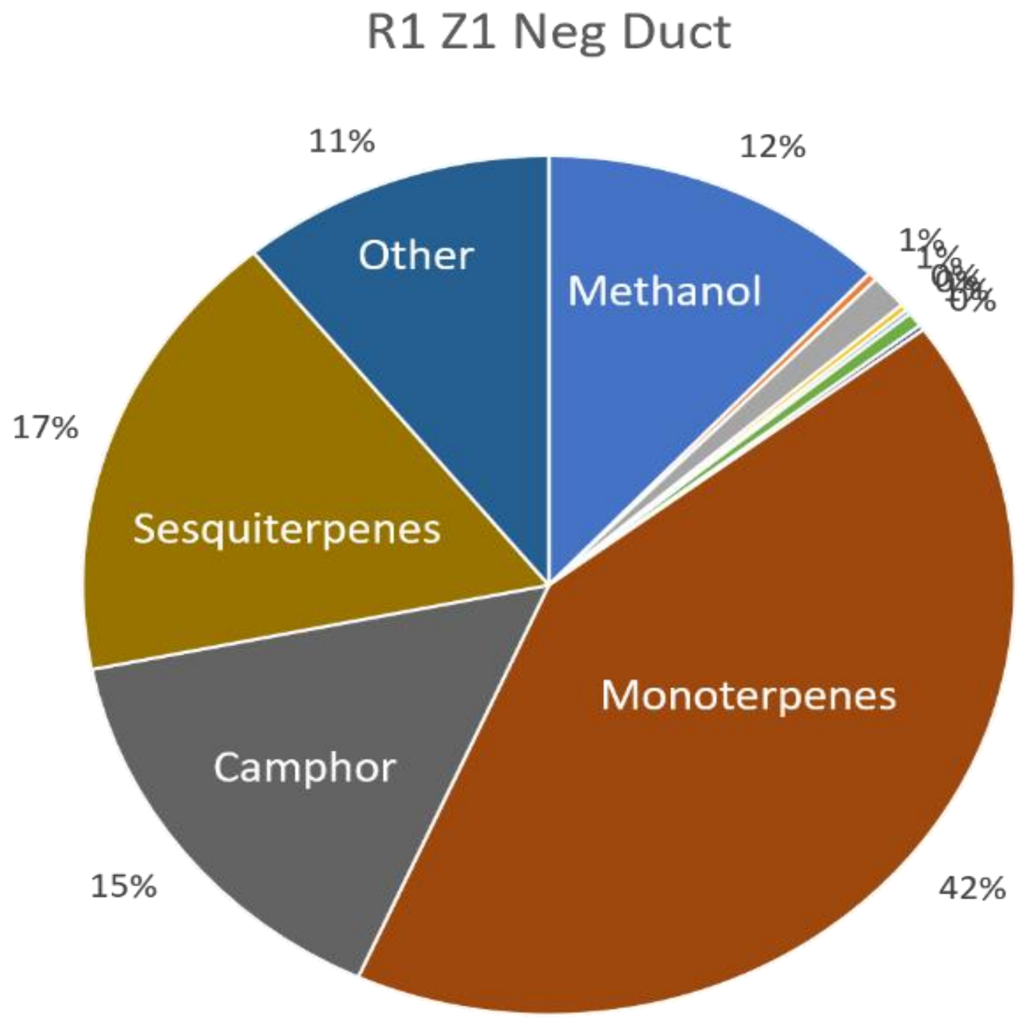
Mass Compounds Emitted through Duct

Compound	Formula	Actual lbs	Method 25.3 lbs as CH_4
Methanol	CH_4O	0.17	0.09
Formic acid /ethanol	CH_2O_2	0.11	0.04
Acetic acid	$C_2H_4O_2$	0.13	0.07
Propanoic acid	$C_3H_6O_2$	0.04	0.03
Butanoic acid	$C_4H_8O_2$	0.05	0.03
Acetone	C_3H_6O	0.03	0.02
2-butanone	C_4H_8O	0.19	0.17
pentanones	$C_4H_6O_2$	0.03	0.03
Monoterpenes	$C_{10}H_{16}$	0.19	0.22
$C_{10}H_{16}O$	$C_{10}H_{16}O$	0.01	0.01
Sesquiterpenes	$C_{15}H_{24}$	0.04	0.05
	Total	**0.99**	**0.76**
	lbs VOC / wet ton	**0.05**	**0.04**

0.065 lbs VOC / wet ton

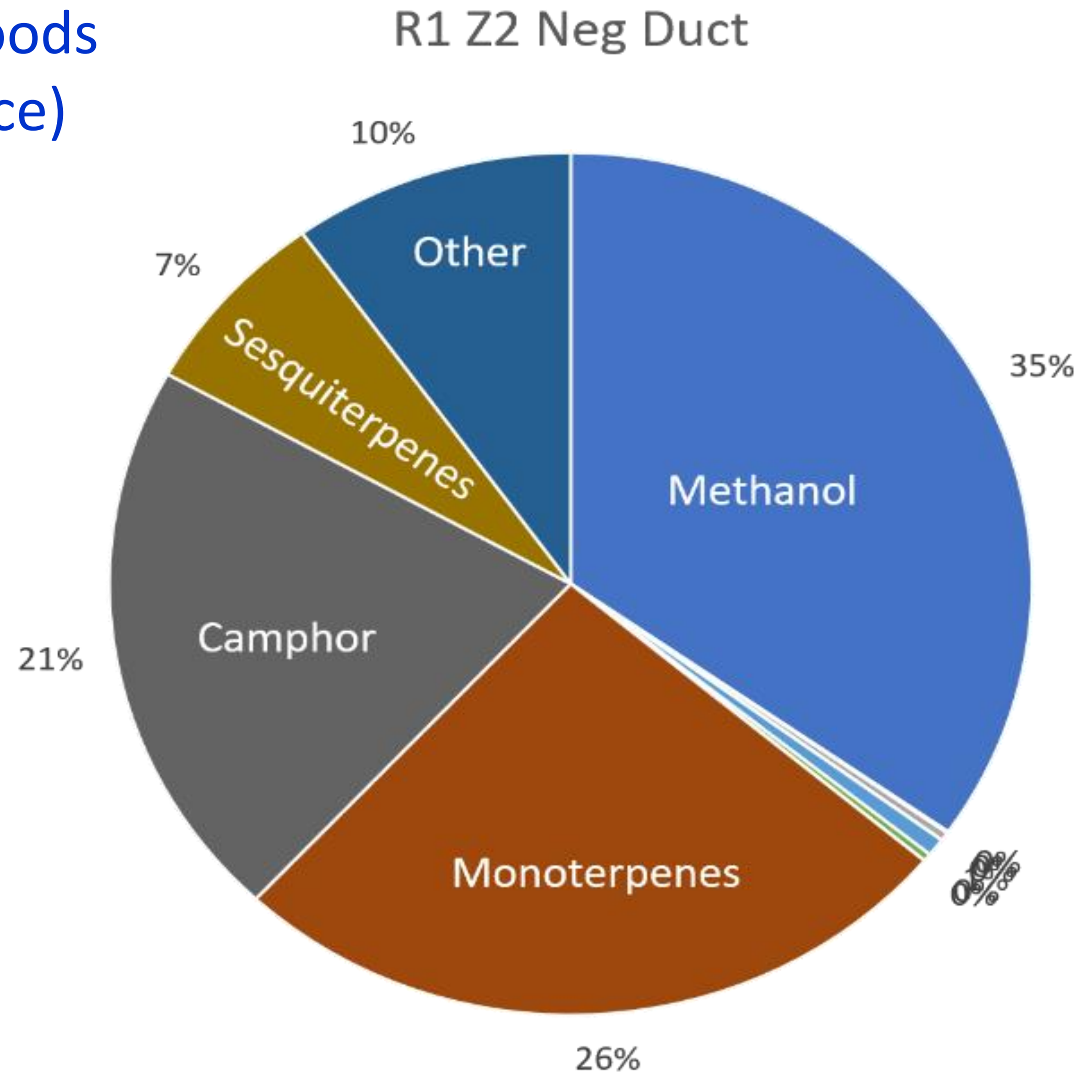
Green Waste Only
Softwoods (spruce)

3.5 CFM / CY



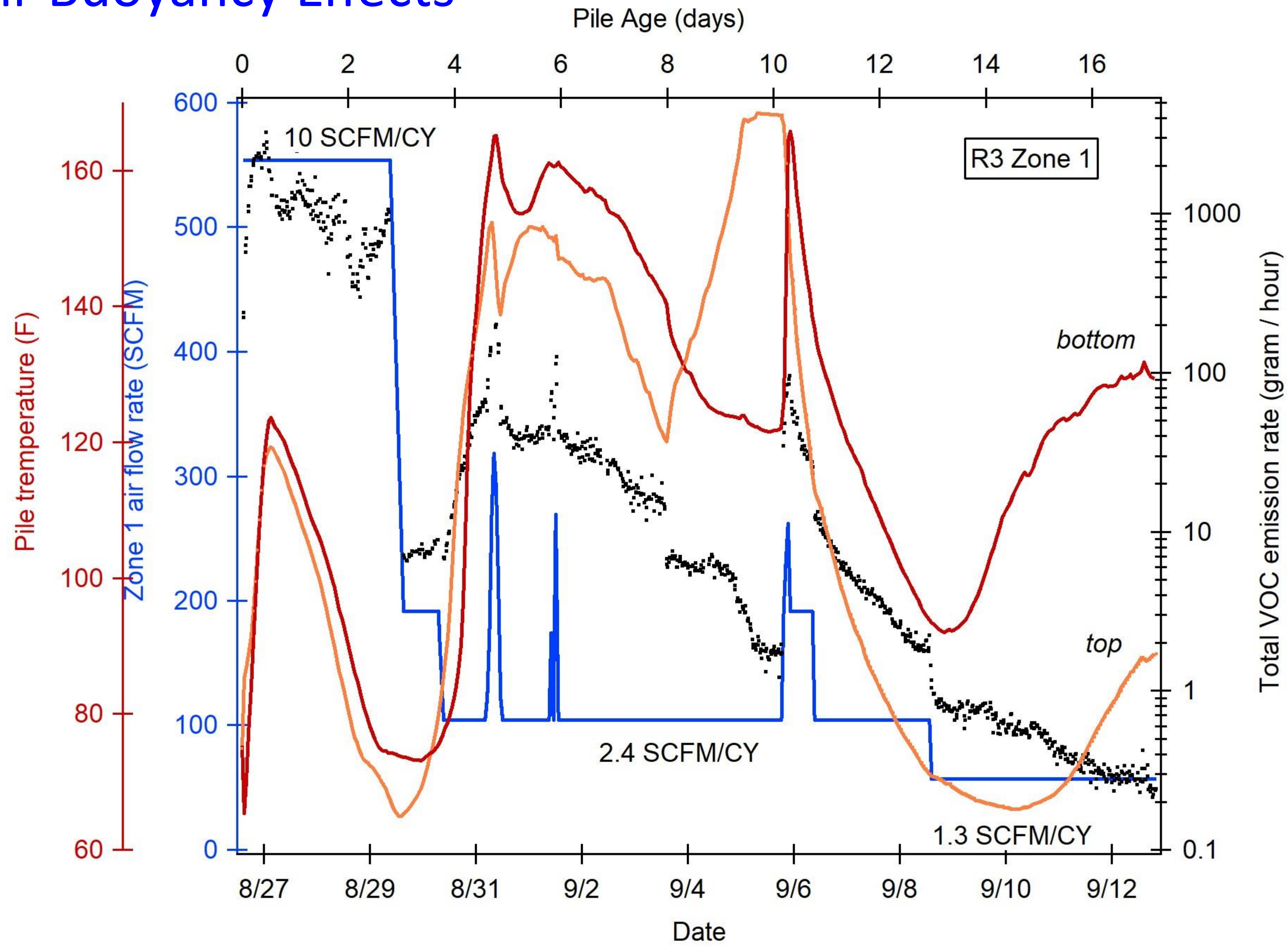
126 °F Average pile temp and 19.5% O_2
4.9 lbs VOC

1.5 CFM / CY



151 °F Average pile temp and 16.3% O_2
7.8 lbs VOC

Air Buoyancy Effects



R3 Zone 1 Negative Aeration

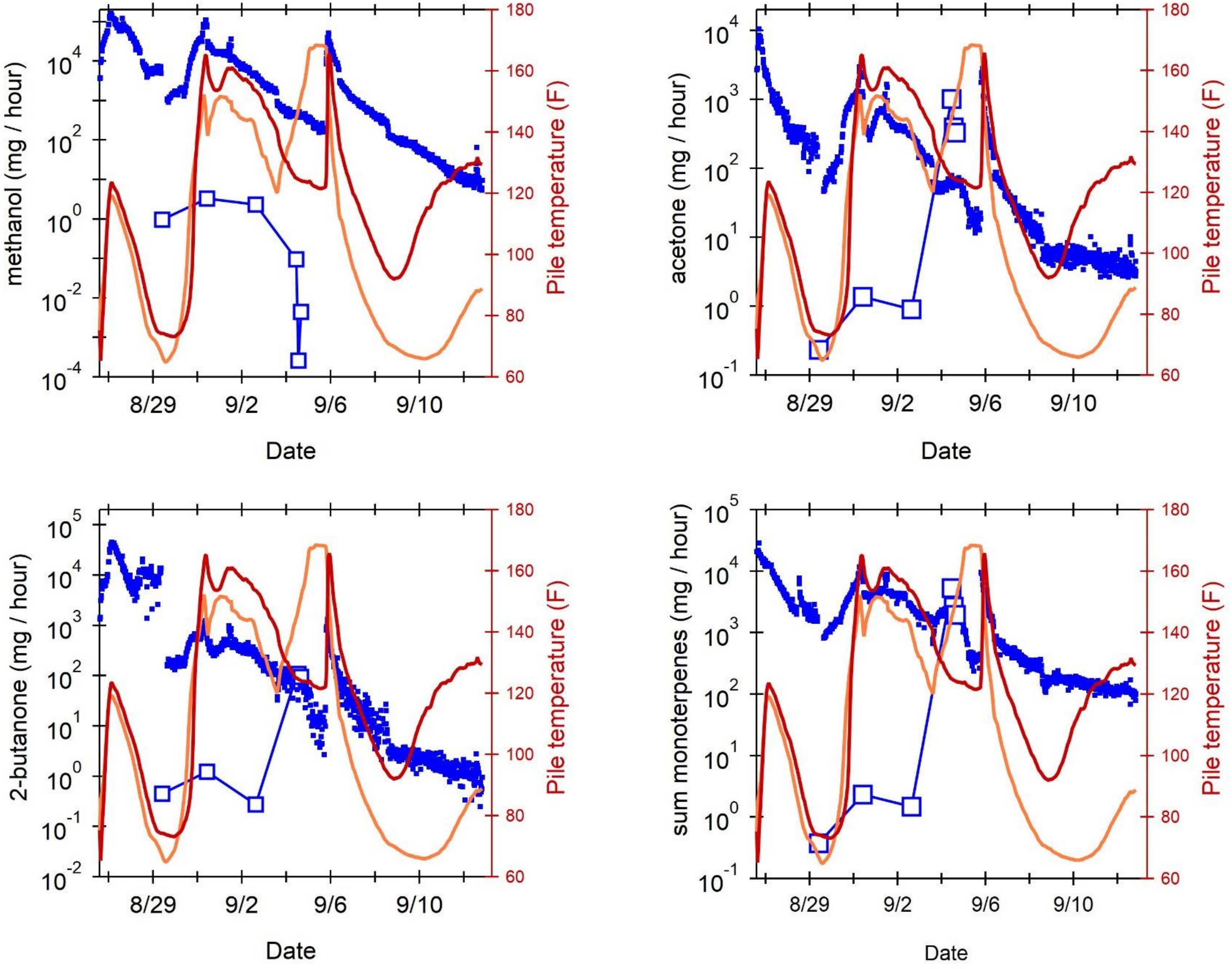
Top pile temp increases rapidly on Sept 3 afternoon for a day or so until damper opens up on Sept 5.

Sept 3 Increase in **top temp** causes factor 3 decrease in duct emissions.

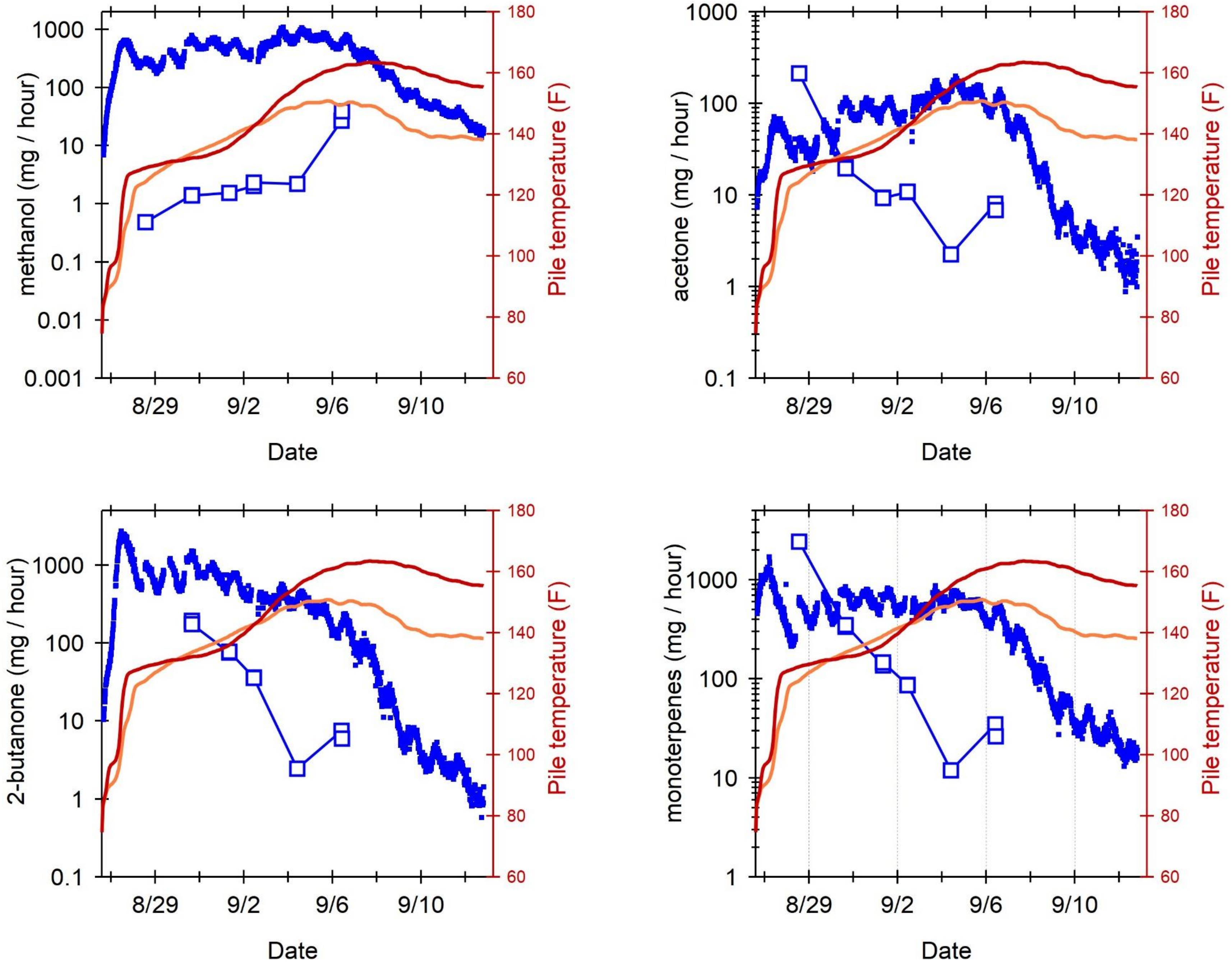
Air buoyancy moving some VOC emission out of top surface rather than through duct?

Influence of Air Buoyancy on Pile Surface Flux

R3 Zone 1



- Surface flux emission rates (blue squares) much lower than duct (blue dots) except on Sept 5 sampling day when pile average top temperature was greater than average bottom temperature (buoyancy effect).
- Average pile top temperature increased from 120 F to 170 F in 48 hours.
- Monoterpene flux increased by factor of 3600, 2-butanone by a factor of 350, and acetone by factor of 150. Methanol flux decreased!?
- Influence of compound solubility - less soluble compounds can rise with hot air through the pile to surface.



R3 Zone 2: Negative aeration: low flow

Pile emission rates from Duct and Pile Surface

VOC surface emission rates decrease with pile age.

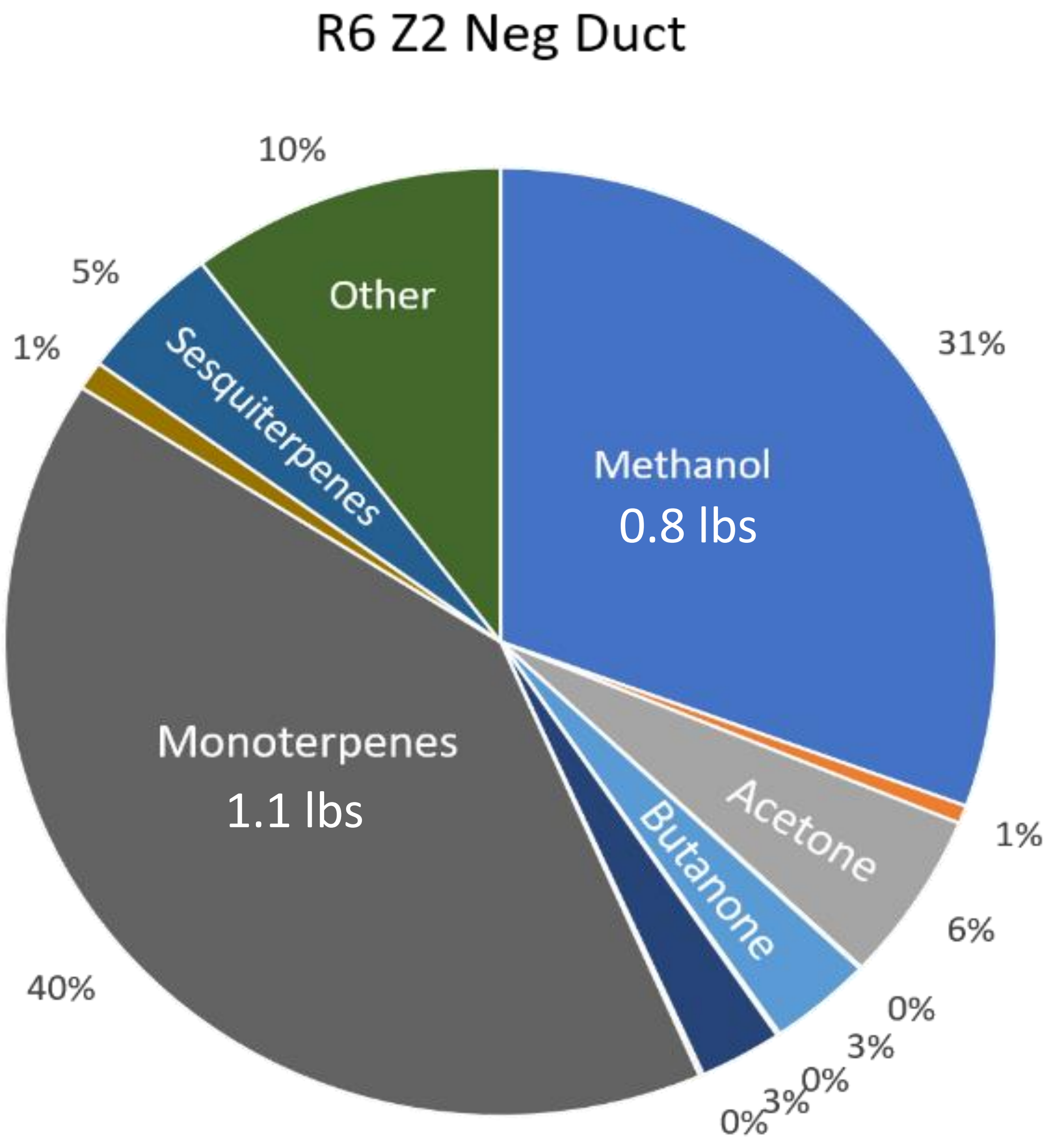
Pile surface emission typically much lower than duct emissions.

Table of Duct Emission Factors for Negatively Aerated Piles

	Mass emitted (lbs)		Emission Factor (lbs VOC / wet ton)		Air flow first 2 days (SCFM/CY)		Average air flow remaining days (SCFM / CY)		Average pile temperature (°F)		Average pile O_2 level (%)		
Run #	**Z 1**	**Z2**	**Z 1**	**Z 2**	**Z1**	**Z 2**	**Z 1**	**Z 2**	**Z 1**	**Z 2**	**Z1**	**Z2**	
R1*	3.91	6.22	0.25	0.39	19	1.8	3.8	0.9	126	151	19.5	16.6	
R3*	25.7	0.99	**1.35**	**0.05**	**13**	**0.3**	2.4	0.3	113	143	19.2	14.2	Factor of ~30 difference
R4		14.2		0.66		3.8		1.2		141		18.9	
R5		4.65		0.26		4.1		0.8		142		15.7	
R6		2.38		0.10		**1.1**		1.2		158		14.4	Wet lower air flow
R7		22.2		1.20		**3.7**		1.5		139		19.0	Dry higher air flow

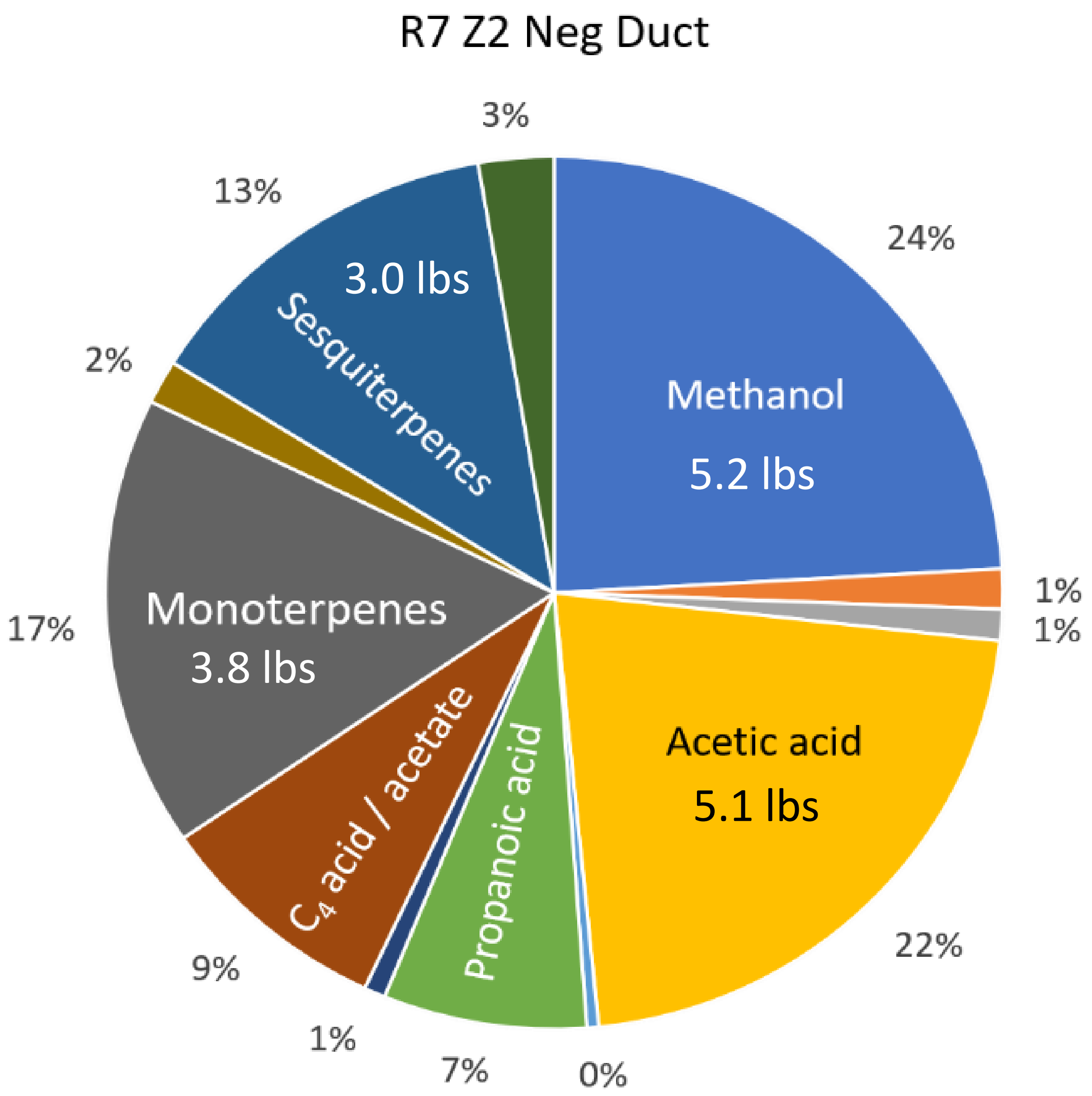
* Measurement duty cycle < 100%, emissions underestimated.

Wet pile, less food, older GW, lower air flow rates



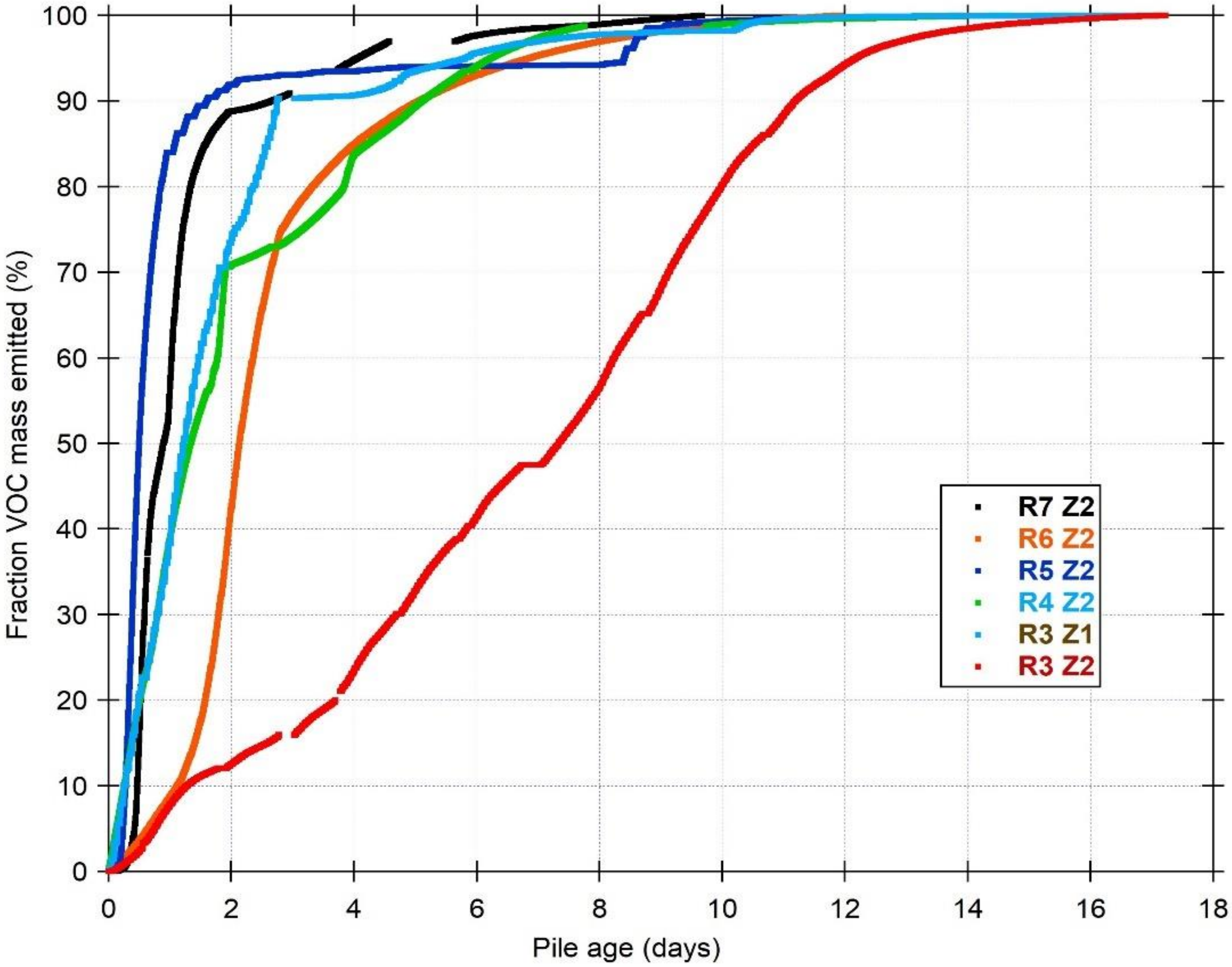
0.10 lbs VOC thru duct / wet ton

Dry pile, more food, fresher GW, higher air flow rates



1.2 lbs VOC thru duct / wet ton

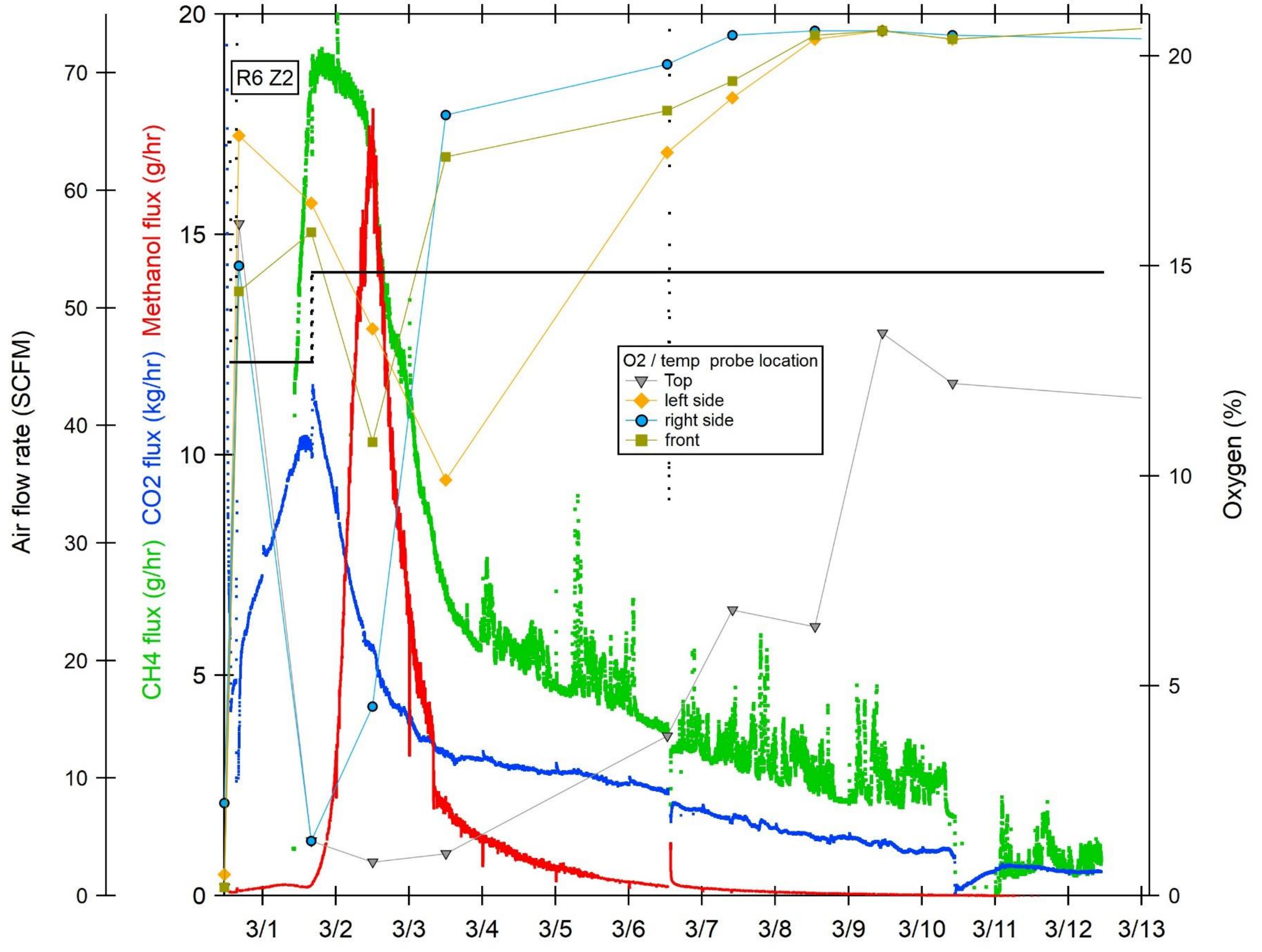
Fraction Total VOC Mass Emitted through duct versus Pile Age



Majority of emissions emitted in the first 4 days.

R3 Z2 very low air flow pile, R6 Z2 lower air flow; emissions spread out over time (more like windrow).

GHG Emissions & Oxygen



R6 Zone 2

Negative aeration mode

Duct mass flux and % O_2 measurements from O_2/temp probe at 4 locations in the pile.

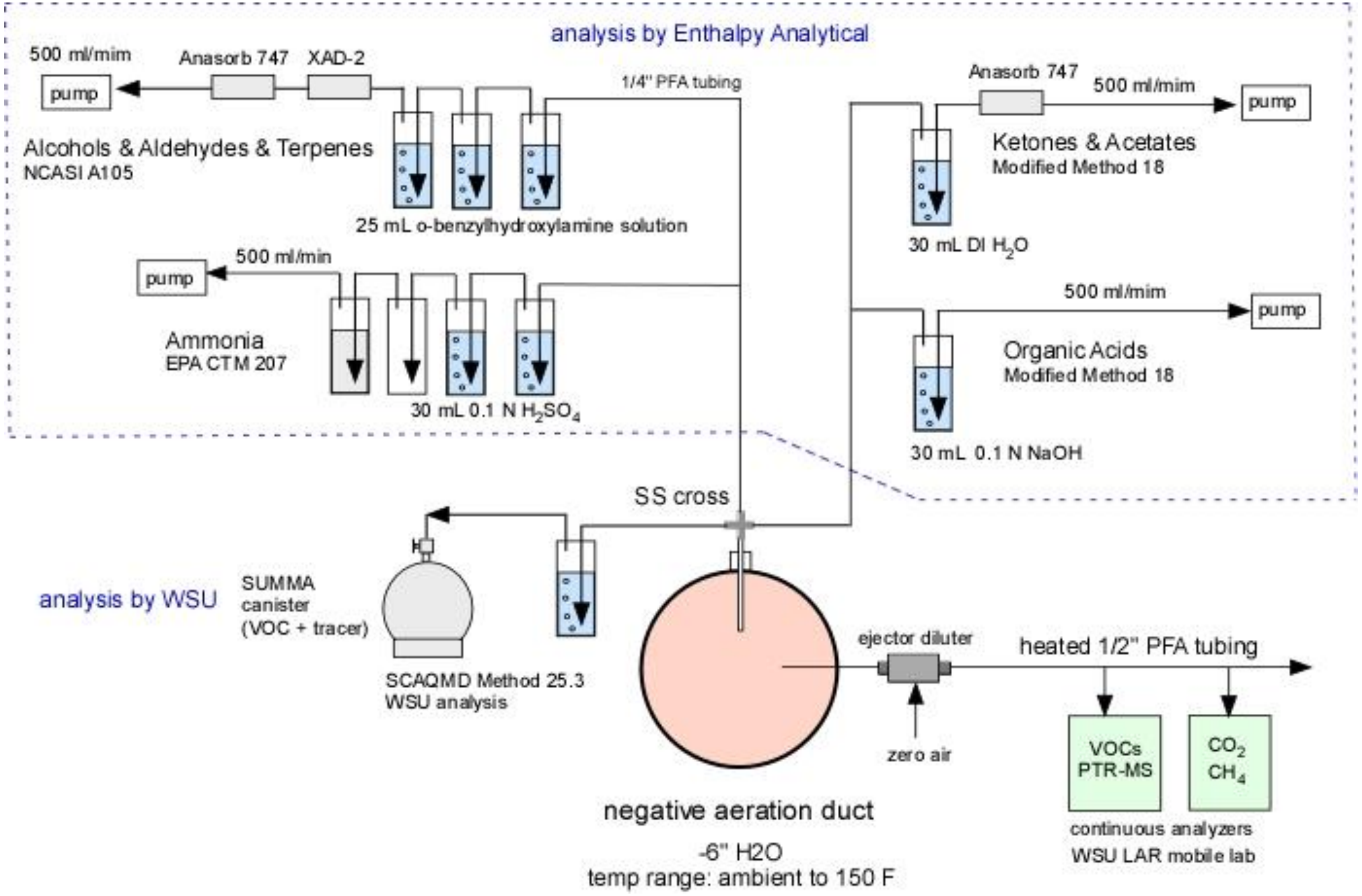
End of pile measured by Top probe location has lower O_2 (not as well aerated?). Pile aeration not uniform.

CO_2, CH_4, and methanol display different temporal behavior.

CO emission rate ~ 0.03% of CO_2.

New Emission Study 2023-2024 biennium

Do it again but added new EPA approved emission test methods

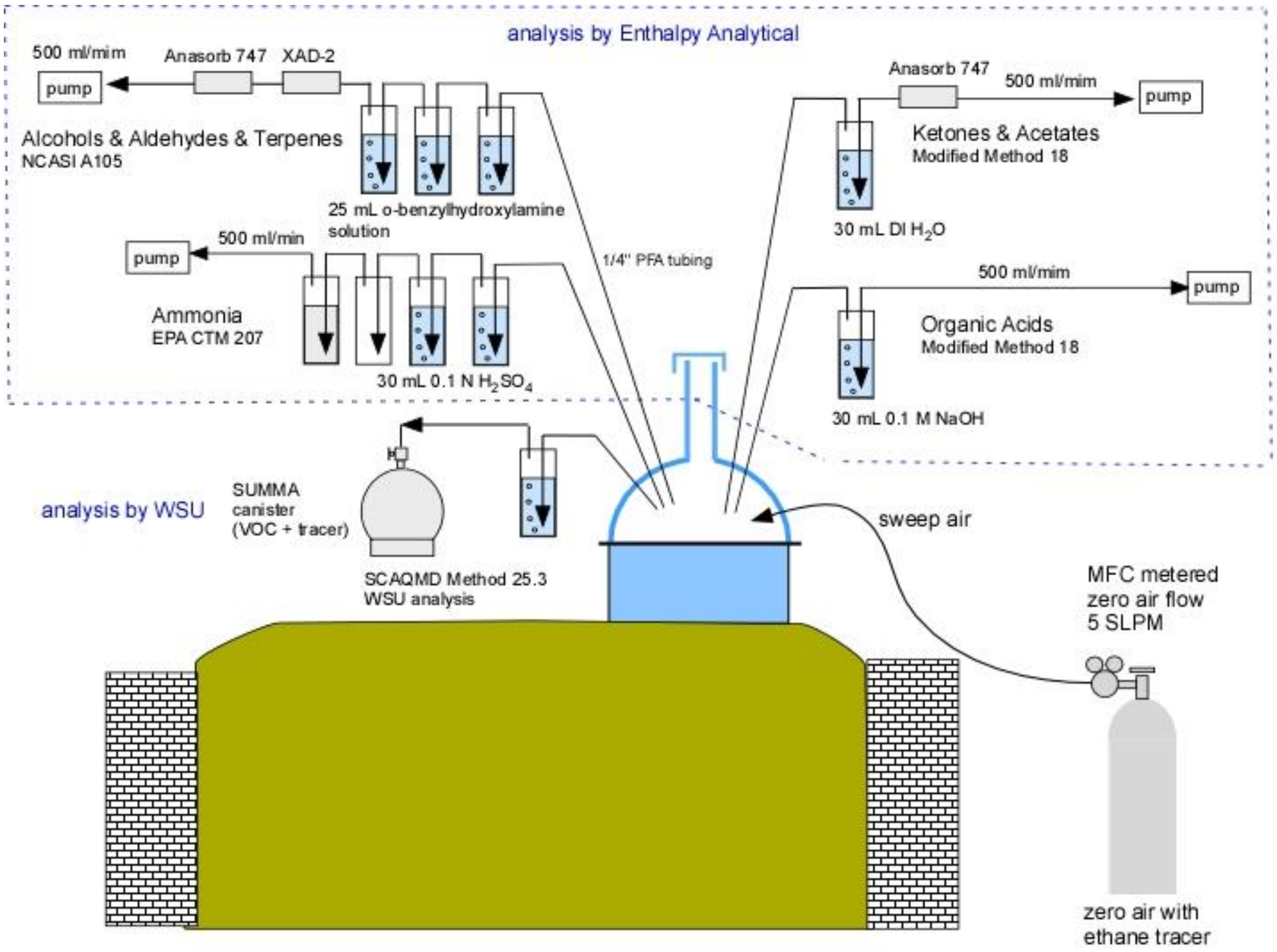


Year 1: Pullman Pilot Plant
Year 2: Puyallup Pilot Plant at WSU Research & Extension Center.

Conduct 4 runs at each site:

- **green waste**
- **green waste / food waste**

- Mimic commercial conditions to best extent possible (temp, air flow rates, pile depth).
- Measure speciated emission rates to determine total VOC emission factor.
- VOC emission factor data needed to determine potential to emit for air permitting.

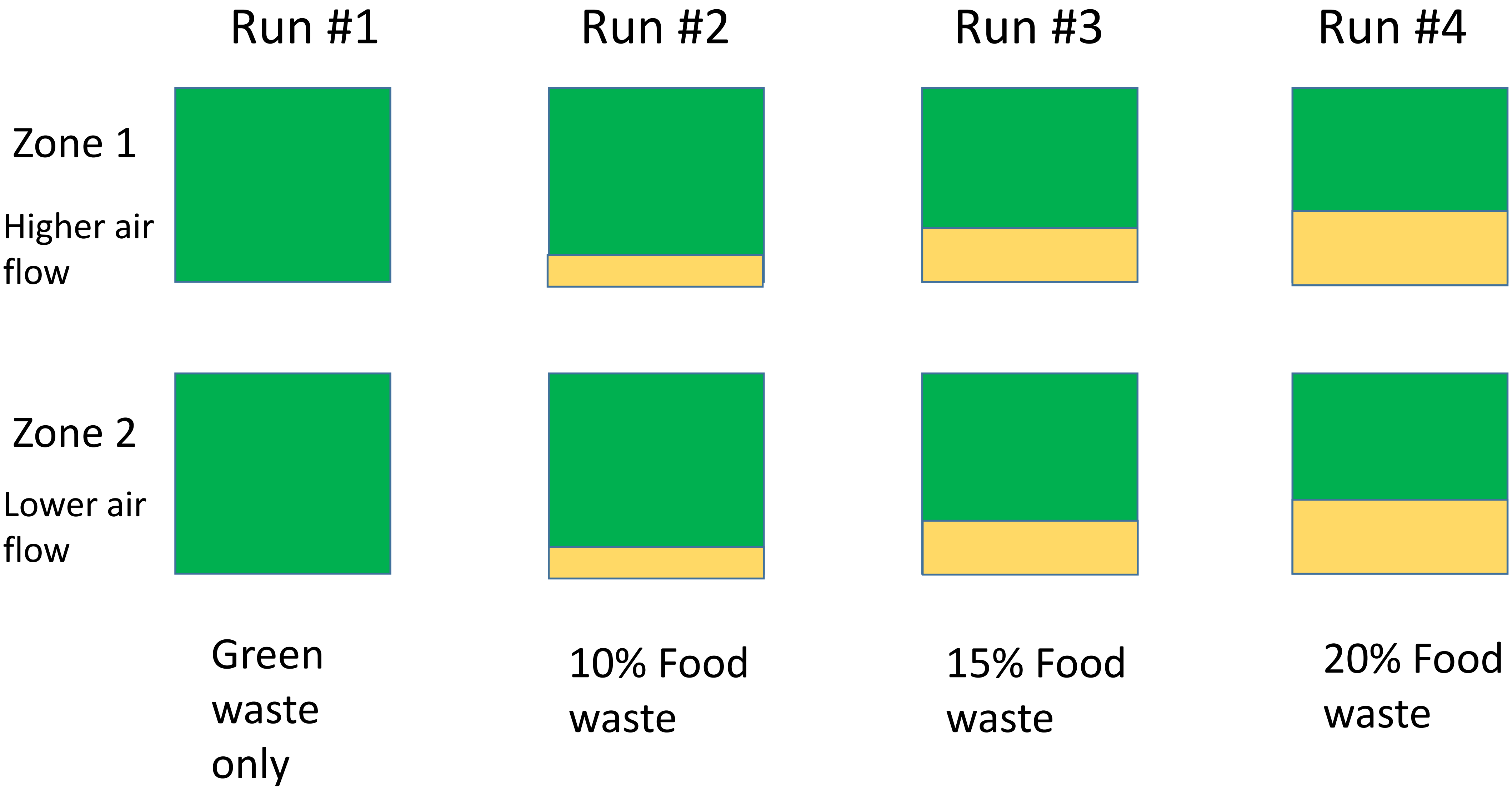


Sampling schedule for duct and each pile surface:
every day (day 1-4)
day 7, 9, 11, 15, 21.

4 sample sets per day.

Perform 4 Runs comparing zones.

Contract lab costs for analysis ~$190,000 for each year.



Run #1
Run #2
Run #3
Run #4
Zone 1
Higher air flow
Zone 2
Lower air flow
Green waste only
10% Food waste
15% Food waste
20% Food waste

Summary

- Average duct VOC emission rate was 0.54 ± 0.50 lbs VOC / wet ton (R4,R5,R6,R7)
  equivalent to 0.39 ± 0.38 lbs VOC as methane / wet ton (Method 25.3 units)

- For negative aeration, the surface flux emission rate usually orders of magnitude lower than duct emission rate.

- Need to balance good air flow rates to manage odor generation and pile temperature with VOC emission rates.

- Future testing – paired tests with 4 different feedstocks (% GW, % FW)?

Acknowledgments

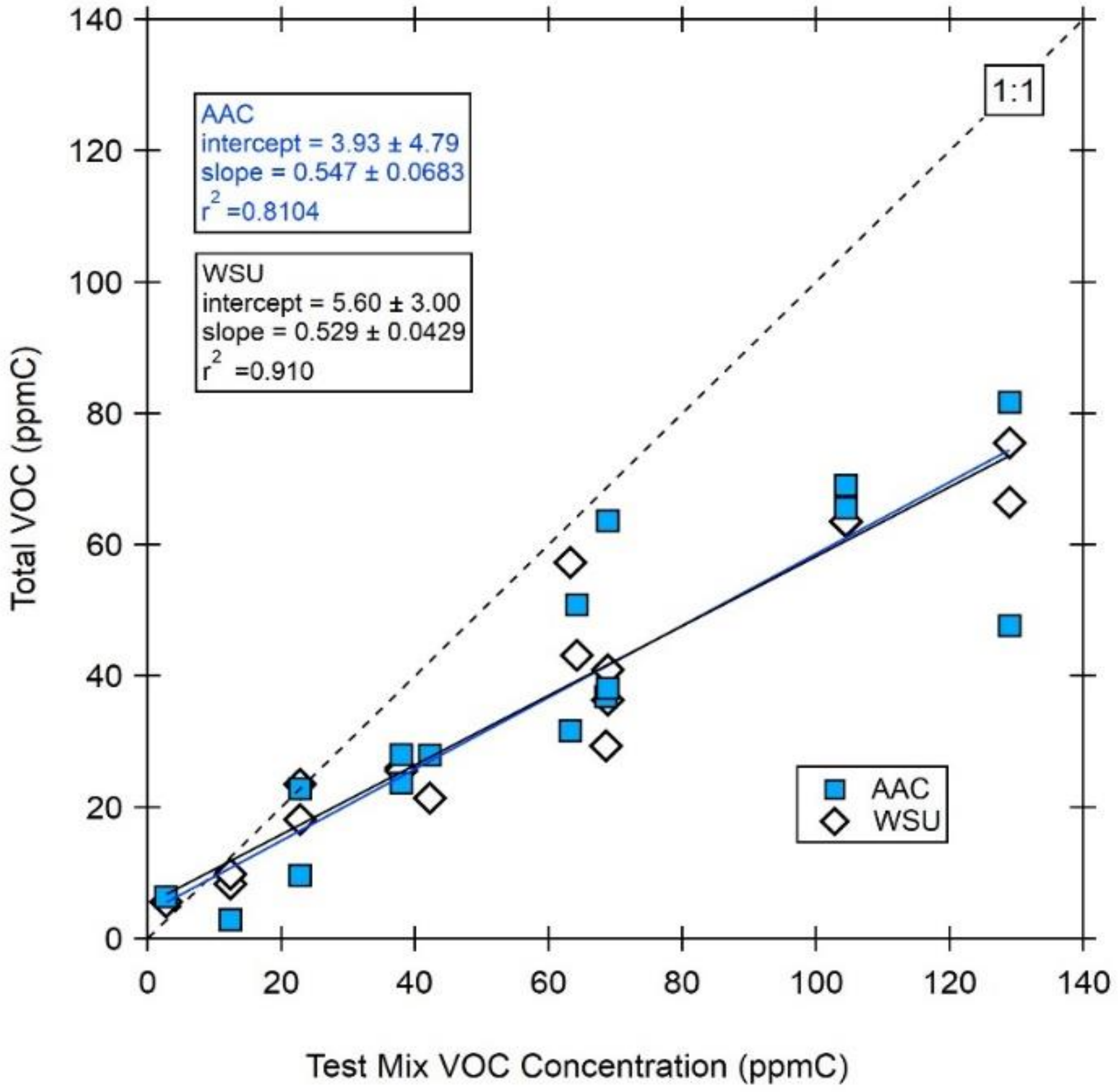
Project was a lot of work and wouldn't have happened with out the following people:

- Collaborator Tim O'Neil – Engineered Compost Systems (Seattle, WA)

WSU team

- Patrick O'Keeffe - WSU scientific assistant (pilot plant build, van equipment, sampling, …)
- Rhonda Skaggs - WSU part-time research assistant (GC-MS analysis)
- Dheapika Vijyakumar – graduate student (TOC analysis)
- WSU Compost Yard - Rick Finch & Ron Redman
  - yard operators Jake Reeves and Brett Rode

SCAQMD Method 25.3?



Method 25.3 under reported VOC test mix concentration by factor of 2.