APPENDIX B

Air Quality and Greenhouse Gas Emissions Calculations

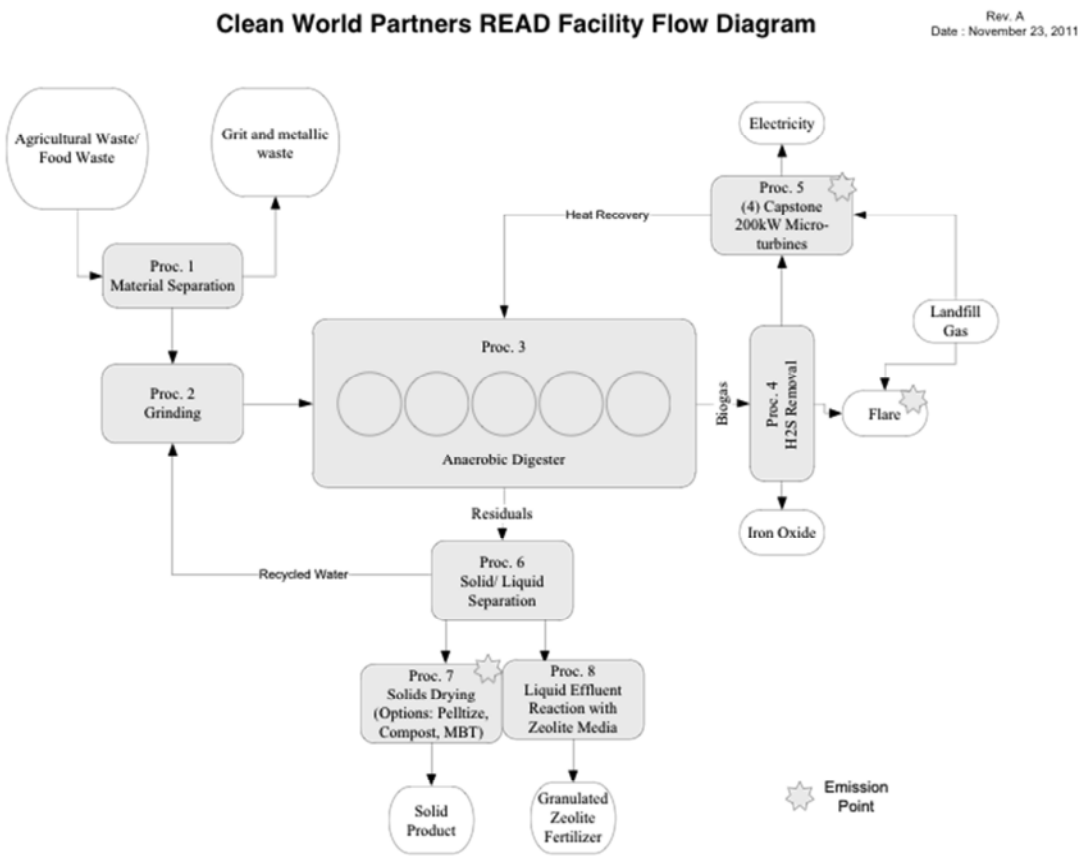
UC Davis Anaerobic Digester Emissions

System Setup and Process Flow

U.C. Davis, partnering with Clean World Partners (CWP), is proposing a Renewable Energy Anaerobic Digester (READ) co-located with the U.C. Davis landfill for energy production from agriculture and food waste, the organic component of municipal solid waste, and landfill gasses. The proposed project site is located at the former campus landfill, in the southwestern corner of the UC Davis campus. The READ facility is planned to be built in two phases – the Phase 1 facility is designed to process 25 ton per day (TPD) and Phase 2 will expand the facility to accept 50 TPD. This report addresses the air pollution emission from both the Phase 1 and Phase 2 facilities as separate facilities, not as an upgrade from Phase 1 to Phase 2.

Figure 1 shows the process flow diagram for the READ facility. The stars on the diagram represent air emissions points.

Figure 1. Process Flow Diagram



Emissions Sources

Flare

Biogas flares are integral parts of any anaerobic digester system to address the issue of biogas production in the event of a system shutdown, power failure, or other planned or unplanned process interruptions. Flares are generally designed and sized with a capacity rating higher than the maximum potential biogas output at any given time. System inputs and flare sizing for the READ facility are shown in Table 1 below.

Table 1. READ System Inputs

	Phase 1 – 25 TPD Facility	**Phase 2 – 50 TPD Facility**
Landfill Gas[1]		
Volumetric Flow Rate	130 SCFM	130 SCFM
Heat Content	500 BTU/SCF	500 BTU/SCF
Biogas		
Volumetric Flow Rate	55 SCFM	130 SCFM
Heat Content	650 BTU/SCF	650 BTU/SCF
Totals		
Volumetric Flow Rate	185 SCFM	260 SCFM
Heat Content	544.6 BTU/SCF	575 BTU/SCF
Flare Capacity		
Max. Estimated Heat Rate	6.05 MMBtu/hr	8.97 MMBtu/hr
Factor of Safety (10%)	0.61 MMBtu/hr	0.90 MMBtu/hr
Design Capacity	**6.66 MMBtu/hr**	**9.87 MMBtu/hr**

The approximate makeup of the biogas is:

- BTU value between 550 and 650 BTU/SCF
- 55% to 65% methane (CH4)
- 35% to 45% carbon dioxide (CO2)
- 0% to 2% hydrogen (H2)
- ~1000 ppm hydrogen sulfide (H2S)

H2S will be reduced by the use of an iron sponge system to be installed between the digester and the flare. The inlet H2S concentrations to the H2S treatment unit is estimated at 1,000 PPM and specified not to exceed 50 PPM from the outlet of the H2S treatment unit. The flare will combust the biogas after the H2S treatment occurs.

The approximate makeup of the landfill gas is:

- BTU value between 450 and 550 BTU/SCF[2]
- 45% to 55% methane (CH4) [3]

[1] Currently landfill gas from the collocated U.C. Davis landfill is either flared (under permit P-14-98 from the Yolo-Solano AQMD) or used as boiler fuel by the nearby UC Davis Primate Center

[2] Estimate from Clean World Partners

- 45% to 55% carbon dioxide (CO_2) [4]
- 0% to 2% hydrogen (H_2)
- ~50 ppm hydrogen sulfide (H_2S) [5]

After the anaerobic digester biogas leaves the H_2S treatment unit, the composition is similar to that of the biogas from the landfill gas. The combined anaerobic digester biogas and landfill gas mixture will be referred to as biogas.

Emissions are estimated based on flare capacity and emissions factors from AP-42 and from previously permitted CWP biogas flares for a food waste anaerobic digester in Sacramento County.[6] Expected emissions are indicated on Table 2.

Table 2. Expected READ Flare Emission

	NOx	SOx	PM10	PM2.5	CO	VOC*
Emissions Factors [lbs./MMBtu]	0.068	0.0149	0.0137	0.0137	0.37	0.063
Phase 1 – 25 TPD						
Lbs./hr	0.453	0.099	0.091	0.091	2.464	0.420
Lbs/day	10.869	2.382	2.190	2.190	59.141	10.070
Lbs./qtr.	991.8	217.3	199.8	199.8	5,396.6	918.9
Lbs./year	3,967.2	869.3	799.3	799.3	21,586.4	3,675.5
Phase 2 – 50 TPD						
Lbs./hr	0.671	0.147	0.135	0.135	3.652	0.622
Lbs/day	16.108	3.530	3.245	3.245	87.646	14.923
Lbs./qtr.	1,469.8	322.1	296.1	296.1	7,997.7	1,361.8
Lbs./year	5,879.4	1,288.3	1,184.5	1,184.5	31,990.6	5,447.1

*VOCs do not include methane and averages from AP-42 Table 13.5-1 and 13.5-2 are used to calculate the emissions factor for VOCs.

Microturbines

The READ facility is proposing Capstone C200 (www.microturbine.com) microturbines to generate both heat and electricity. Each microturbine has an operational capacity of 200 kW and produces three-phase power at 480VAC and 60Hz with an approximate 33% electrical efficiency and a net heat rate of 10,300 Btu/kWh. Heat can be recovered from the exhaust gas in the form of hot water. Phase 1 will utilize three (3) microturbines and Phase 2 will use four (4) microturbines.

[3] Calculated with ± 5% error from the assumptions found in the EPA Landfill Gas Emissions Model (LandGEM) Version 3.02 found on: http://www.epa.gov/ttn/catc/products.html#software

[4] Calculated with ± 5% error from the assumptions found in the EPA Landfill Gas Emissions Model (LandGEM) Version 3.02 found on: http://www.epa.gov/ttn/catc/products.html#software

[5] Calculated with ± 5% error from the assumptions found in the EPA Landfill Gas Emissions Model (LandGEM) Version 3.02 found on: http://www.epa.gov/ttn/catc/products.html#software

[6] Sacramento Metropolitan Air Quality Management District Authority to Construct No. 23238 and No. 232289

The Capstone C200 microturbine is CARB Certified (see Appendix A). Table 3 shows the maximum emissions limits for a CARB certified microturbine.

Table 3. CARB Maximum Emissions Limits for Capstone C200

	NOx	CO	VOC	PM	SOx	CO2
Lbs./MWh	0.5	6.0	1.0	-	-	-
Lbs./hr	0.125	1.5	0.25	-	-	-
Lbs./day	3.0	36	6.0	-	-	-
Lbs./qtr.	273.75	3,285.0	547.5	-	-	-
Lbs./year	1,095.0	13,140.0	2,190.0	-	-	-

Using the CARB Certification emissions limits, for Phase 1, the three Capstone microturbines would emit 9 lbs./day (3,285 lbs./year) of NOx, 108 lbs./day (39,420 lbs/year) of CO, and 18 lbs./day (6,570 lbs./year) of VOC. In Phase 2, with four Capstone microturbines, emissions would be 12 lbs./day (4,380 lbs./year) of NOx, 144 lbs./day (52,560 lbs./year) of CO, and 24 lbs./day (8,760 lbs./year) of VOC.

Compost Digestate

Digestate is the term for the byproduct that is augured out of the anaerobic digester. Digestate can be used for plant fertilizer, alternative animal bedding, low-grade building products such as fiberboard, and as a peat moss substitute for local nurseries and turf grass growers. The digestate is stabilized and composted. Emissions factors for uncontrolled compost (open air compost instead of a controlled anaerobic digestion) have not been sufficiently identified in test studies[7]. The data available comes from a San Joaquin Valley Air Pollution Control District (SJVAPCD) Report from June 2008 titled: "*Organic Material Composting and Drying focusing on Greenwaste Compost: Air Emissions Data Review*."[8] Table 4 shows the relevant data collected by SJVAPCD for composting food waste (the material that is an input into the anaerobic digester) and Table 5 shows the relevant data collected by SJVAPCD for composting biosolids with green waste bulking agents (wood waste). Note that the difference between the food waste numbers and biosolids numbers is because biosolids have already had one cycle of decomposition and digestion.

Table 4. Emissions Factors for Uncontrolled Compost of Food Waste

Technology	VOC [lbs./ton-day]	NH3 [lbs./ton-day]
AgBag	37.1	0.7
Compostex	26.9	8.1
Micropore 30	10.8	14.2
Micropore 45	3.4	1.4

Table 5. Emissions Factors for Uncontrolled Compost of Biosolids

[7] SJVAPCD Policy SSP2050 p.7 http://www.valleyair.org/policies_per/Policies/SSP2050.pdf
[8] http://www.arb.ca.gov/cc/compost/documents/rule4566_emissions_factor_report.pdf

Technology	VOC [lb/ton]	NH3 [lb/ton]
Uncovered	3.7	4.6
Micropore	0.2	1.8
Biofilter	0.2	0.1
Biofilter at 80% efficiency*	0.74	0.92

* SJVAPCD has used 80% efficiency for biofilters. The table shows biofilter emissions as an 80% reduction from uncovered.

Compost emissions are based on the total amount of on-site compost. Estimations are for a worst case scenario of 90 day retention time. The emissions factors indicated above are based on total emissions per ton per compost cycle. These factors are not daily rates and cannot be averaged over the compost cycle to estimate daily emissions due to significant initial spikes in VOC and NH3 emissions during the first week of compost. See Organic Material Composting and Drying focusing on Greenwaste Compost Air Emissions Data Review (Appendix C) for details.

Composting cycles range from 45 to 90 days. With a 90 day maximum retention period, a steady-state emissions rate will be achieved equal to that of the full composting cycle. Therefore, to calculate maximum emission rates, the value shown in Table 4 and Table 5 can be used as a daily emissions factor when multiplied by the daily introduction of digestate to the system.

To determine the digestate emissions factors, the values from Table 5 will be used for the estimate. Digestate represents food waste after anaerobic digestion. Therefore the food waste numbers indicated in Table 4 are not appropriate for the digestate analysis because they represent the input into the anaerobic digester, not the output. Table 5, biosolids, are much closer to the actual composition of digestate because the material has already been through the first stage of digestion and has been mixed with a wood based bulking agent.

The READ facility expects maximum digestation production at the rate of 17.9 tons per day for a maximum total storage of 1,611 tons. CWP does not intend to use a bulking agent. Table 6 displays the expected emissions from digestate.

Table 6. Expected Maximum Emissions from Digestate

	Phase 1 – 25 TPD		Phase 2 – 50 TPD	
	VOC	**NH3**	**VOC**	**NH3**
Uncovered				
Lb/ton	3.7	4.6	3.7	4.6
Lb/hr	1.38	1.72	2.76	3.43
Lb/day	33.1	41.2	66.2	82.3
Lb/qtr.	3,021.7	3,756.8	6,043.5	7,513.5
Lb/year	12,0867.0	15,027.1	24,174.0	30,054.1
Micropore				
Lb/ton	0.2	1.8	0.2	1.8
Lb/hr	0.07	0.67	0.15	1.34
Lb/day	1.79	16.11	3.58	32.22
Lb/qtr.	163.3	1470.0	326.7	2940.1
Lb/year	653.4	5,880.2	1,306.7	11,760.3
Biofilter				
Lb/ton	0.2	0.1	0.2	0.1
Lb/hr	0.07	0.04	0.15	0.07
Lb/day	1.79	0.90	3.58	1.79
Lb/qtr.	163.3	81.7	326.7	163.30
Lb/year	653.4	326.7	1,306.7	653.4
Biofilter at 80% efficiency*				
Lb/ton	0.74	0.92	0.74	0.92
Lb/hr	0.28	0.34	0.55	0.69
Lb/day	6.62	8.23	13.25	16.47
Lb/qtr.	604.3	751.4	1,208.7	1,502.7
Lb/year	2,417.4	3,005.4	4,834.8	6,010.8

* SJVAPCD has used 80% efficiency for biofilters. The table shows biofilter emissions as an 80% reduction from uncovered.

Total Expected Emissions

Table 7 summarizes the total emissions expected from the READ facility. Phase 1 will employ one flare rated for 6.66 MMBtu/hr, three Capstone C200 microturbines, and a biofilter with 80% efficiency for the digestate. Phase 2 will employ one flare rated for 9.87 MMBtu/hr, four Capstone C200 microturbines, and a biofilter with 80% efficiency for the digestate.

It should be noted that the total emissions for either Phase 1 and Phase 2 listed in Table 7 below are a combination of the flare emissions and the four 200 KW microturbines. It is very unlikely that the full capacity flare and all four of the microturbines would ever be operating at the same time, thus the Table 7 represents the "worst case" scenarios for air emissions.

Table 7. Total Expected Maximum Emissions

Phase 1 – 25 TPD							
	NOx	**SOx**	**PM10**	**PM2.5**	**CO**	**VOC**	**NH3**
Flare [lb/day]	10.87	2.38	2.19	2.19	59.14	10.07	-
Microturbine [lb/day]	9.00	-	-	-	108.00	18.00	-
Digestate [lb/day]	-	-	-	-	-	6.62	8.23
Total [lb/day]	**19.87**	**2.38**	**2.19**	**2.19**	**167.14**	**34.69**	**8.23**
Total [lb/year]	**7,252.6**	**868.7**	**799.4**	**799.4**	**61,006.1**	**12,661.9**	**3,004.0**
Phase 2 – 50 TPD							
	NOx	**SOx**	**PM10**	**PM2.5**	**CO**	**VOC**	**NH3**
Flare [lb/day]	16.11	3.53	3.25	3.25	87.65	14.92	-
Microturbines [lb/day]	12.00	-	-	-	144.00	24.00	-
Digestate [lb/day]	-	-	-	-	-	13.25	16.47
Total [lb/day]	**28.11**	**3.53**	**3.25**	**3.25**	**231.65**	**52.17**	**16.47**
Total [lb/year]	**10,260.2**	**1,288.5**	**1,186.3**	**1,186.3**	**84,552.3**	**19,042.1**	**6,011.6**

UC Davis Renewable Energy Anaerobic Digester
Stationary Source Emissions
Flare

Flare Data		
Landfill Gas Flow	-	SCF/hour
Heat Content	-	Btu/scf
Biogas Gas Flow	7,500	SCF/hour
Heat Content	650	Btu/scf
Operational hours:	24	hr/day
	8,760	hr/yr
Capacity Factor:	100%	
Standard Temp	60	deg F
Molar Volume	379.70	scf/mole

Table STA-1
Flare Emissions

Units	Greenhouse Gases			
	CO_2	CH_4	N_2O	CO_2e
ppm @ 3% O_2				
lbs/MMBtu	114.79	0.0022	0.0002	114.91
lbs/hr	559.62	0.01	0.00	560.18
lbs/day	13,430.98	0.26	0.03	4,906.07
lbs/yr	4,902,307.34	94.15	9.41	4,907,203.05
tons/yr	2,451.15	0.05	0.00	2,453.60
metric tons/yr	2,223.65	0.04	0.00	2,225.87

Notes:
1. Emission factors for CO_2, CH_4, and N_2O: California Climate Action Registry, *General Reporting Protocol*, Version 3.1, (2009) 101, 103.
2. Emissions of CO_2e assumes the following global warming potentials: CO_2 = 1, CH_4 = 21, N_2O = 310.

UC Davis Renewable Energy Anaerobic Digester
Stationary Source Emissions
Microturbines

Turbine Data		
Nominal Rating of Generator:	200.0	kW
Number of New Generators:	4	
Heat rate	10,300	Btu/kWh
Operational hours:	8,760	hr/yr
Capacity Factor:	100%	
MMBtu/yr	72,182.40	

Table STA-2
Microturbine Emissions

Units	Greenhouse Gases			
	CO_2	CH_4	N_2O	CO_2e
kg/MMBtu	52.07	0.001	0.0001	52.12
metric tons/yr	3,758.54	0.07	0.007	3,762.29

Notes:
1. Emission factors for CO_2, CH_4, and N_2O: California Climate Action Registry, *General Reporting Protocol* , Version 3.1, (2009) 101, 103.
2. Emissions of CO_2e assumes the following global warming potentials: CO_2 = 1, CH_4 = 21, N_2O = 310.

UC Davis Renewable Energy Anaerobic Digester
Area Source Emissions
Composting of Digestate

Composting Data

Mass generation of digestate	17.9	tons/day
	5,945	metric tons/year

Table STA-3
Composting Emissions

Units	Greenhouse Gases			
	CO_2	CH_4	N_2O	CO_2e
MTCO2e/MT waste	-	0.09	0.09	0.18
metric tons/yr	-	535.09	535.094	1,070.19

Notes:
1. Emission factors for CO_2, CH_4, and N_2O: California Climate Action Registry, *Organic Waste Composting Project Protocol* , Version 1.0, (2010) 29.

Baseline Landfill Emissions Data

Mass generation of digestate	50.0	tons/day
	16,608	metric tons/year

Table STA-4
Baseline Landfill Emissions

Units	Greenhouse Gases			
	CO_2	CH_4	N_2O	CO_2e
MTCO2e/MT waste	-	0.09	0.09	0.18
metric tons/yr	-	1,494.68	1,494.675	2,989.35

Notes:
1. Emission factors for CO_2, CH_4, and N_2O: California Climate Action Registry, *Organic Waste Composting Project Protocol* , Version 1.0, (2010) 29.