APPENDIX B

Revised Air Quality and Greenhouse Gas Emissions Calculations

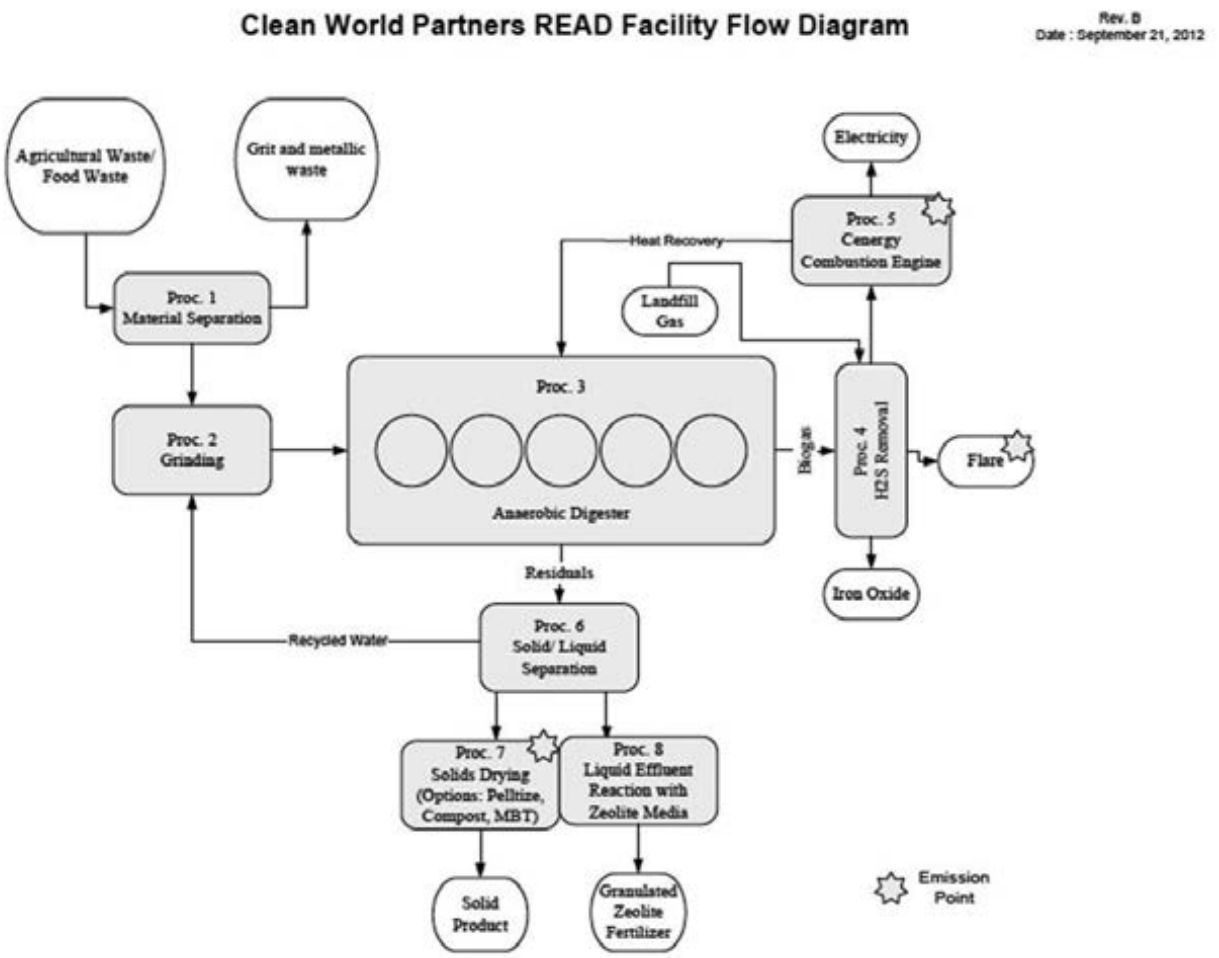
UC Davis Anaerobic Digester Emissions

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%)	0.60 MMBtu/hr	0.90 MMBtu/hr
Design Capacity	**6.65 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 (CH_4)
- 35% to 45% carbon dioxide (CO_2)
- 0% to 2% hydrogen (H_2)
- ~1000 ppm hydrogen sulfide (H_2S)

The approximate makeup of the landfill gas is:

- BTU value between 450 and 550 BTU/SCF[2]
- 45% to 55% methane (CH_4) [3]
- 45% to 55% carbon dioxide (CO_2) [4]

[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

[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

- 0% to 2% hydrogen (H_2)
- ~50 ppm hydrogen sulfide (H_2S) [5]

H2S will be reduced by the use of an iron sponge system to be installed between the digester and the flare. The landfill gas will be mixed with the gas from the anaerobic digester before reaching the iron sponge system. 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 mixture of anaerobic digester biogas and landfill gas that leaves the H2S treatment unit will be referred to as biogas throughout this paper.

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

	NO_x	SO_x	PM_{10}	$PM_{2.5}$	CO	VOC*
Emissions Factors [lbs./MMBtu]	0.068	0.0149	0.0137	0.0137	0.37	0.063
Phase 1 – 25 TPD						
Lbs./hr	0.452	0.099	0.091	0.091	2.460	0.419
Lbs./day	10.852	2.378	2.186	2.186	59.048	10.054
Lbs./qtr.	990.2	217.0	199.5	199.5	5388.1	917.4
Lbs./year	3,961.0	867.9	798.0	798.0	21,552.4	3,669.7
Phase 2 – 50 TPD						
Lbs./hr	0.671	0.147	0.135	0.135	3.651	0.622
Lbs./day	16.103	3.528	3.244	3.244	87.619	14.919
Lbs./qtr.	1469.4	322.0	296.0	296.0	7995.2	1361.3
Lbs./year	5,877.6	1,287.9	1,184.2	1,184.2	31,980.9	5,445.4

*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.

Internal Combustion Engines

The READ facility is proposing 2G-Cenergy internal combustion (IC) engines (www.2g-cenergy.com) to generate both heat and electricity. For the first phase, the READ facility proposes one (1) 2G 800 BG, 800kW, IC engine and for the second phase, the original IC engine will be replaced with one (1) 2G 1200 BG, 1200kW, IC engine. Each engine produces three-phase power at 480VAC and 60Hz with an approximate 41.5% electrical efficiency and a net heat rate of approximately 8,200 Btu/kWh. The engines are designed for CHP utilization and

[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

have thermal efficiencies of approximately 44.4% with 921 kW and 1,374 kW of useable thermal output respectively.

The 2G-Cenergy IC engines will be fitted with Selective Catalytic Reduction (SCR) emissions controls manufactured by 2G-Cenergy. 2G-Cenergy stated that there is a 91% reduction in NO_x emissions and 73% reduction in CO emissions. Table 3 shows the expected emissions based on vendor specifications.

Table 3. Maximum Emissions Limits for 2G-Cenergy IC Engines[7]

	NO_x	SO_x[8]	PM_{10}[9]	$PM_{2.5}$[10]	CO	VOC
Emissions Factors [g/bhp-h]	0.1	-	-	-	0.68	0.27
Emissions Factors [lb/MWh]	0.3	0.002	0.0003	0.0003	2.0	0.8
Phase 1 – 25 TPD						
Lbs/hr	0.2	0.0016	0.0002	0.0002	1.6	0.6
Lbs/day	5.6	0.04	0.01	0.01	38.1	15.1
Lbs/qtr	511.8	3.5	0.5	0.5	3,480.1	1,381.8
Lbs/year	2,047.1	14.0	1.8	1.8	13,920.5	5,527.3
Phase 2 – 50 TPD						
Lbs/hr	0.4	0.0024	0.0003	0.0003	2.4	0.9
Lbs/day	8.4	0.06	0.01	0.01	57.2	22.7
Lbs/qtr	767.7	5.3	0.7	0.7	5,220.2	2,072.7
Lbs/year	3,070.7	21.0	2.8	2.8	20,880.8	8,290.9

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[11]. 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*

[7] Engine emissions data from 2G-Cenergy website: http://www.2g-cenergy.com/PDFs/Product%20Program%20Cogen%20Biogas%2060Hz.pdf and SCR reduction efficiency from email correspondence with Phillip Turwitt, 2G-Cenergy.
[8] SO_x Emissions Factor from US EPA AP-42 Table 3.2-2
[9] PM Emissions Factor from US EPA AP-42 Table 3.2-2
[10] PM Emissions Factor from US EPA AP-42 Table 3.2-2
[11] SJVAPCD Policy SSP2050 p.7 http://www.valleyair.org/policies_per/Policies/SSP2050.pdf

Greenwaste Compost: Air Emissions Data Review."[12] 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 Compost of Food Waste

Technology	VOC [lb/ton-day]	NH_3 [lb/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 Compost of Biosolids

Technology	VOC [lb/ton]	NH_3 [lb/ton]
Uncovered	3.7	4.6
Micropore	0.2	1.8
ASP/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, is much closer to the actual composition of digestate because the material has already been through the first stage of

[12] SJVAPCD "Organic Material Composting and Drying focusing on Greenwaste Compost Air Emissions Data Review" http://www.arb.ca.gov/cc/compost/documents/rule4566_emissions_factor_report.pdf

digestion and has been mixed with a wood based bulking agent. In co-composting, the bulking agent, greenwaste, has higher emission factors than biosolids[13].

The READ 50 TPD facility expects maximum digestation production at the rate of 17.9 tons per day for a maximum total storage of 1,611 tons. CWP may use a bulking agent dependent on the digestate composition. Worst case amount of bulking agent required has been determined to be 8.75 tons per day yielding a daily total of 26.85 tons per day or over the maximum storage time of 90 days, a total of 2,417 tons. The READ 25 TPD facility anticipates producing digestate and utilizing bulking agents at a rate equal to half the value discussed foe the READ 50 TPD facility. Table 6 displays the expected emissions from digestate.

Table 6. Expected Maximum Emissions from Digestate

	Phase 1 – 25 TPD		**Phase 2 – 50 TPD**	
	VOC	**NH_3**	**VOC**	**NH_3**
Uncovered				
Lb/ton	3.7	4.6	3.7	4.6
Lb/hr	2.07	2.57	4.14	5.15
Lb/day	49.67	61.76	99.35	123.51
Lb/qtr.	4,532.6	5,635.1	9,065.2	11,270.3
Lb/year	18,130.5	22,540.6	36,260.9	45,081.2
Micropore				
Lb/ton	0.2	1.8	0.2	1.8
Lb/hr	0.11	1.01	0.22	2.01
Lb/day	2.69	24.17	5.37	48.33
Lb/qtr.	245.0	2,205.1	490.0	4,410.1
Lb/year	980.0	8,820.2	1,960.1	17,640.5
Biofilter				
Lb/ton	0.2	0.1	0.2	0.1
Lb/hr	0.11	0.06	0.22	0.11
Lb/day	2.69	1.34	5.37	2.69
Lb/qtr.	245.0	122.5	490.0	245.0
Lb/year	980.0	490.0	1,960.1	980.0
Biofilter at 80% efficiency*				
Lb/ton	0.74	0.92	0.74	0.92
Lb/hr	0.41	0.51	0.83	1.03
Lb/day	9.93	12.35	19.87	24.70
Lb/qtr.	906.5	1,127.0	1,813.0	2,254.1
Lb/year	3,626.1	4,508.1	7,252.2	9,016.2

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

[13] SJVAPCD "Organic Material Composting and Drying focusing on Greenwaste Compost Air Emissions Data Review" http://www.arb.ca.gov/cc/compost/documents/rule4566_emissions_factor_report.pdf and SCAQMD "Technology Assessment for Proposed Rule 1133: Emissions Reductions from Composting and Related Operations" http://www.aqmd.gov/rules/doc/r1133/r1133_techassessment.pdf

Bulking Agent Transport

For the READ 50 TDP facility, when the bulking agent is required, the bulking agent will be delivered to the facility via heavy-duty diesel trucks capable of hauling 25 tons. The expected round-trip delivery distance is 50 miles. Given the worst case scenario requiring 8.75 tons per day of bulking agent, approximately one truck every three days would be required. On an annual basis this results in 127.75 truck deliveries covering 6,387.5 miles. The READ 25 TPD facility anticipates half the deliveries and therefore half of the miles driven annually. Table 7 calculates the expected annual emission from bulking agent truck delivery.

Table 7. Expected Emissions from Bulking Agent Delivery

	NO_x	SO_x	PM_{10}	$PM_{2.5}$	CO	VOC
Emission Factors[14] [lbs./mi]	0.068	0.0149	0.0137	0.0137	0.37	0.063
Phase 1 – 25 TPD						
Lbs./hr	0.011	0.00001	0.001	0.000	0.004	0.001
Lbs./day	0.27	0.0004	0.01	0.01	0.09	0.02
Lbs./qtr	24.7	0.03	1.2	1.0	8.1	2.0
Lbs./year	98.7	0.1	4.8	4.2	32.6	8.0
Phase 2 – 50 TPD						
Lbs./hr	0.023	0.00003	0.001	0.001	0.007	0.002
Lbs./day	0.54	0.001	0.03	0.02	0.18	0.04
Lbs./qtr	49.3	0.1	2.4	2.1	16.3	4.0
Lbs./year	197.4	0.3	9.6	8.3	65.2	16.0

Total Expected Emissions

Table 8 summarizes the total emissions expected from the READ facility. Phase 1 will employ one flare rated for 6.65 MMBtu/hr, one 2G 800 BG 2G-Cenergy IC Engine, and a biofilter with 80% efficiency for the digestate. Phase 2 will employ one flare rated for 9.87 MMBtu/hr, one 2G 1200 BG 2G-Cenergy IC Engine, and a biofilter with 80% efficiency for the digestate. When running, the READ facility will operate under one of three scenarios:

1) All the biogas is flared and the digestate is produced
2) All the biogas is run to the microturbine and the digestate is produced
3) Some of the biogas is flared, some is run to the turbines, and the digestate is produced.

In scenario 3, when the biogas is diverted to both the microturbine and the flare, the expected emissions from the equipment scales proportionately with the volume of biogas delivered. Due to the linear relationship between biogas input and emissions, scenario 1 or scenario 2 will

[14] SCAQMD "Highest (Most Conservative) EMFAC2007 (version 2.3) Emissions Factors for On-Road Heavy-Heavy-Duty Diesel Trucks" http://www.aqmd.gov/ceqa/handbook/onroad/onroad.html

represent the maximum emissions for any given pollutant. Table 8 and Table 9 indicate these two scenarios.

Table 8. Total Expected Maximum Emissions – Scenario 1: all Flare, no IC Engine

Phase 1 – 25 TPD							
	NO_x	**SO_x**	**PM_{10}**	**$PM_{2.5}$**	**CO**	**VOC**	**NH_3**
Flare [lbs./day]	10.852	2.378	2.186	2.186	59.048	10.054	-
IC Engine [lbs./day]	-	-	-	-	-	-	-
Digestate** [lbs./day]	-	-	-	-	-	9.93	12.35
Truck [lbs./day]	0.27	0.0004	0.01	0.01	0.09	0.02	-
Total [lbs./day]	**11.12**	**2.38**	**2.20**	**2.20**	**59.14**	**20.01**	**12.35**
Total [lbs./year]	**4,059.7**	**868.0**	**802.8**	**802.2**	**21,584.9**	**7,303.8**	**4,508.1**
Phase 2 – 50 TPD							
	NO_x	**SO_x**	**PM_{10}**	**$PM_{2.5}$**	**CO**	**VOC**	**NH_3**
Flare [lbs./day]	16.103	3.528	3.244	3.244	87.619	14.919	-
IC Engine [lbs./day]	-	-	-	-	-	-	-
Digestate** [lbs./day]	-	-	-	-	-	19.87	24.70
Truck [lbs./day]	0.54	0.001	0.03	0.02	0.18	0.04	-
Total [lbs./day]	**16.64**	**3.53**	**3.27**	**3.27**	**87.80**	**34.83**	**24.70**
Total [lbs./year]	**6,074.9**	**1,288.1**	**1,193.7**	**1,192.5**	**32,046.1**	**12,713.6**	**9,016.2**

** Digestate Emissions Factors with a biofilter are used from Table 6

Table 9. Total Expected Maximum Emissions – Scenario 2: no Flare, all IC Engine

Phase 1 – 25 TPD							
	NO_x	**SO_x**	**PM_{10}**	**$PM_{2.5}$**	**CO**	**VOC**	**NH_3**
Flare [lbs./day]	-	-	-	-	-	-	-
IC Engine [lbs./day]	5.6	0.04	0.01	0.01	38.1	15.1	-
Digestate** [lbs./day]	-	-	-	-	-	9.93	12.35
Truck [lbs./day]	0.27	0.0004	0.01	0.01	0.09	0.02	-
Total [lbs./day]	**5.88**	**0.04**	**0.02**	**0.02**	**38.23**	**25.10**	**12.35**
Total [lbs./year]	**2,145.8**	**14.1**	**6.6**	**6.0**	**13,953.1**	**9,161.3**	**4,508.1**
Phase 2 – 50 TPD							
	NO_x	**SO_x**	**PM_{10}**	**$PM_{2.5}$**	**CO**	**VOC**	**NH_3**
Flare [lbs./day]	-	-	-	-	-	-	-
IC Engine [lbs./day]	8.4	0.1	0.01	0.01	57.2	22.7	-
Digestate** [lbs./day]	-	-	-	-	-	19.87	24.70
Truck [lbs./day]	0.54	0.001	0.03	0.02	0.18	0.04	-
Total [lbs./day]	**8.95**	**0.06**	**0.03**	**0.03**	**57.39**	**42.63**	**24.70**
Total [lbs./year]	**3,268.1**	**21.3**	**12.3**	**11.1**	**20,945.9**	**15,559.1**	**9,016.2**

** Digestate Emissions Factors with a biofilter are used from Table 6

Table 10 highlights the maximum expected emissions for each pollutant from both scenario 1 and scenario 2.

Table 10. Total Expected Maximum Emissions – Scenario 1 and Scenario 2

Phase 1 – 25 TPD							
	NO_x	**SO_x**	**PM_{10}**	**$PM_{2.5}$**	**CO**	**VOC**	**NH_3**
Total [lbs./day]	11.12	2.38	2.20	2.20	59.14	25.10	12.35
Total [lbs./year]	4,059.7	868.0	802.8	802.2	21,584.9	9,161.3	4,508.1
Total [tons/year]	**2.03**	**0.43**	**0.40**	**0.40**	**10.79**	**4.58**	**2.25**
Phase 2 – 50 TPD							
	NO_x	**SO_x**	**PM_{10}**	**$PM_{2.5}$**	**CO**	**VOC**	**NH_3**
Total [lbs./day]	16.64	3.53	3.27	3.27	87.80	42.63	24.70
Total [lbs./year]	6,074.9	1,288.1	1,193.7	1,192.5	32,046.1	15,559.1	9,016.2
Total [tons/year]	**3.04**	**0.64**	**0.60**	**0.60**	**16.02**	**7.78**	**4.51**