APPENDIX 3.5

Detailed Calculations of Emissions from WENT Landfill Extension, Existing WENT Landfill, and Marine Vessels

Detailed Calculation of NO_2, SO_2 and RSP Emissions from WENT Landfill Extension

Landfill gas used in Thermal Destructor in ASP	4500 m^3/hr
Landfill gas to be flared in LFG Flare System	52750 m^3/hr
Landfill gas used in LFG Power Generator	750 m^3/hr
Max. landfill gas generated from WENT Extension	58000 m^3/hr

According to Table 4.4 of USEPA Air Emission from Municipal Solid Waste Landfills - Background Information for Proposed Standards and Guidelines, March 1991 (EPA-450/3-90-011a):

Secondary NOx emission from boiler (Thermal Destructor)	70.0 lb/MM scf LFG
Secondary NOx emission from enclosed flare/incinerator (LFG Flare System)	4.9 lb/MM scf LFG
Secondary NOx emission from gas turbine (LFG Power Generator)	26.4 lb/MM scf LFG

Unit Conversion:

1 MM scf
= 1000000 scf
= 28316.847 scm
* scf = Standard Cubic Foot ; scm = Standard Cubic Meter

1 lb/MM scf
= 453.6 g/MM scf
= 0.0160187 g/scm

Standard Conditions (US standard):

60 F
= 15.555556 C
= 288.55556 K

Assume LFG at typical ambient temperature:

25 C
= 298 K

Therefore,

1 m^3 at 25C
= 0.9683072 scm

Landfill gas used in Thermal Destructor in ASP

(*NOx emission from boiler (Thermal Destructor)
= 1.121311 g/scm)

4500 m^3/hr
= 4357.3826 scm/hr
= 1.210384 scm/sec
NOx Emission = **1.3572173 g/sec**

Landfill gas to be flared in LFG Flare System

(*NOx emission from enclosed flare/incinerator (LFG Flare System)
= 0.078492 g/scm)

52750 m^3/hr
= 51078.207 scm/hr
= 14.188391 scm/sec
NOx Emission = **1.1136722 g/sec**

Landfill gas used in LFG Power Generator

(*NOx emission from gas turbine (LFG Power Generator)
= 0.422895 g/scm)

750 m^3/hr
= 726.23043 scm/hr
= 0.2017307 scm/sec
NOx Emission = **0.0853108 g/sec**

Similarly, with reference to Table 4.4 of USEPA Air Emission from Municipal Solid Waste Landfills - Background Information for Proposed Standards and Guidelines, March 1991 (EPA-450/3-90-011a):

Secondary SO2 emission from boiler (Thermal Destructor)	3.0 lb/MM scf LFG
Secondary SO2 emission from enclosed flare/incinerator (LFG Flare System)	3.0 lb/MM scf LFG
Secondary SO2 emission from gas turbine (LFG Power Generator)	3.0 lb/MM scf LFG

Secondary PM (RSP) emission from boiler (Thermal Destructor)	Negligible lb/MM scf LFG
Secondary PM (RSP) emission from enclosed flare/incinerator (LFG Flare System)	Negligible lb/MM scf LFG
Secondary PM (RSP) emission from gas turbine (LFG Power Generator)	37.0 lb/MM scf LFG

Therefore,

Landfill gas used in Thermal Destructor in ASP

SO_2 Emission = **0.0581665 g/sec**
PM (RSP) Emission = **Negligible g/sec**

Landfill gas to be flared in LFG Flare System

SO_2 Emission = **0.6818401 g/sec**
PM (RSP) Emission = **Negligible g/sec**

Landfill gas used in LFG Power Generator

SO_2 Emission = **0.0096944 g/sec**
PM (RSP) Emission = **0.1195644 g/sec**

Detailed Calculation of NO_2, SO_2 and RSP Emissions from Existing WENT Landfill

Landfill gas used in Thermal Destructor in ASP	2500 m^3/hr
Landfill gas to be flared in LFG Flare System	690 m^3/hr
Landfill gas used in LFG Power Generator	750 m^3/hr
Max. landfill gas generated from WENT Extension	3940 m^3/hr

According to Table 4.4 of USEPA Air Emission from Municipal Solid Waste Landfills - Background Information for Proposed Standards and Guidelines, March 1991 (EPA-450/3-90-011a):

Secondary NOx emission from boiler (Thermal Destructor)	70.0 lb/MM scf LFG
Secondary NOx emission from enclosed flare/incinerator (LFG Flare System)	4.9 lb/MM scf LFG
Secondary NOx emission from gas turbine (LFG Power Generator)	26.4 lb/MM scf LFG

Unit Conversion:

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1 lb/MM scf
= 453.6 g/MM scf
= 0.0160187 g/scm

Standard Conditions (US standard):

60 F
= 15.555556 C
= 288.55556 K

Assume LFG at typical ambient temperature:

25 C
= 298 K

Therefore,

1 m^3 at 25C
= 0.9683072 scm

Landfill gas used in Thermal Destructor in ASP

(*NOx emission from boiler (Thermal Destructor)
= 1.121311 g/scm)

2500 m^3/hr
= 2420.7681 scm/hr
= 0.6724356 scm/sec
NOx Emission = **0.7540096 g/sec**

Landfill gas to be flared in LFG Flare System

(*NOx emission from enclosed flare/incinerator (LFG Flare System)
= 0.078492 g/scm)

690 m^3/hr
= 668.13199 scm/hr
= 0.1855922 scm/sec
NOx Emission = **0.0145675 g/sec**

Landfill gas used in LFG Power Generator

(*NOx emission from gas turbine (LFG Power Generator)
= 0.422895 g/scm)

750 m^3/hr
= 726.23043 scm/hr
= 0.2017307 scm/sec
NOx Emission = **0.0853108 g/sec**

Similarly, with reference to Table 4.4 of USEPA Air Emission from Municipal Solid Waste Landfills - Background Information for Proposed Standards and Guidelines, March 1991 (EPA-450/3-90-011a):

Secondary SO2 emission from boiler (Thermal Destructor)	3.0 lb/MM scf LFG
Secondary SO2 emission from enclosed flare/incinerator (LFG Flare System)	3.0 lb/MM scf LFG
Secondary SO2 emission from gas turbine (LFG Power Generator)	3.0 lb/MM scf LFG

Secondary PM (RSP) emission from boiler (Thermal Destructor)	Negligible lb/MM scf LFG
Secondary PM (RSP) emission from enclosed flare/incinerator (LFG Flare System)	Negligible lb/MM scf LFG
Secondary PM (RSP) emission from gas turbine (LFG Power Generator)	37.0 lb/MM scf LFG

Therefore,

Landfill gas used in Thermal Destructor in ASP

SO_2 Emission = **0.0323147 g/sec**
PM (RSP) Emission = **Negligible g/sec**

Landfill gas to be flared in LFG Flare System

SO_2 Emission = **0.0089189 g/sec**
PM (RSP) Emission = **Negligible g/sec**

Landfill gas used in LFG Power Generator

SO_2 Emission = **0.0096944 g/sec**
PM (RSP) Emission = **0.1195644 g/sec**

Detailed Calculation of VOC Emissions from WENT Landfill Extension and Existing WENT Landfill

According to the monitoring results from Year 2002 to 2006 at the flare of the existing WENT Landfill, the concentration of Benzene and Vinyl Chloride at inlet are :

Pollutant	Max. Concentration at Inlet (ppmv)	Concentration at Inlet (ug/cu.m)
Vinyl Chloride	0.28	715.7
Benzene	0.8	2565.2

Note: * Calculated by : Conc (in ppmv) / 0.02445 * Molecular Weight (Vinyl Chloride : 62.5 ; Benzene : 78.4)

Owing to the lack of monitoring data for ASP and power generator, reference has been made to the monitoring data from the flare system in the existing WENT Landill, where the control efficiency of 95.4% and 98.1% for halogenated species (i.e. Vinyl Chloride) and non-halogenated species (i.e. Benzene). As a conservative assumption, these control efficiencies for ASP and power generator are assumed to be the same.

WENT Landfill Extension

Facilities	Source ID	Inlet LFG Flow Rate (cu.m/hr)	Emission Concentration (ug/cu.m)		Emission Rate (g/s)	
			Vinyl Chloride	Benzene	Vinyl Chloride	Benzene
Thermal Destructor	XTD1	2250	715.7	2565.2	0.0000206	0.0000305
	XTD2	2250			0.0000206	0.0000305
LFG Flare System	XFS1	17583			0.0001608	0.0002381
	XFS2	17583			0.0001608	0.0002381
	XFS3	17583			0.0001608	0.0002381
LFG Power Generator	XPG1	375			0.0000034	0.0000051
	XPG2	375			0.0000034	0.0000051

Existing WENT Landfill

Facilities	Source ID	Inlet LFG Flow Rate (cu.m/hr)	Emission Concentration (ug/cu.m)		Emission Rate (g/s)	
			Vinyl Chloride	Benzene	Vinyl Chloride	Benzene
Thermal Destructor	ETD1	1250	715.7	2565.2	0.0000114	0.0000169
	ETD2	1250			0.0000114	0.0000169
LFG Flare System	EFS1	230			0.0000021	0.0000031
	EFS2	230			0.0000021	0.0000031
	EFS3	230			0.0000021	0.0000031
LFG Power Generator	EPG1	375			0.0000034	0.0000051
	EPG2	375			0.0000034	0.0000051

Detailed Calculation of Emissions from Marine Vessels

		IETS vessels	IWTS vessels	OITF vessels	WKTS vessels	NLTS vessels	STF vessels [2]
Maneuvering speed (knots)		approximate 6	approximate 6	approximate 8	approximate 8	10	8
Idling period at WENT Landfill berth		21:30 - 17:00	21:00-18:00	11:00-14:30	07:30 - 19:30	08:30 - 09:20	06:00 - 20:00
Number of trip per day		1	1	1	1	1	1
Engine Power	Propulsion Engine	2x662kW	2x662kW	2x485kW	2x1118.5 kW	2x500 kW	2x1118.5 kW
	Auxiliary Engine	2x165kW	2x165kW	2x174kW	2x125 kW	431 kW, 95 kW	2x125 kW
Load Factor during Maneuvering (%)	Propulsion Engine	50%	50%	50%	80%	80%	80%
	Auxiliary Engine	n.a.	n.a.	n.a.	n.a.	65%, 60%	n.a.
Load Factor during Idling at WENT Landfill berth (%)	Propulsion Engine	See Note [1]		n.a.	n.a.	n..a	n.a.
	Auxiliary Engine			20%	n.a.	65%	n.a.
Exhaust height of vent pipe above sea level (m)	Propulsion Engine	8	8	3.5	12	11	12
	Auxiliary Engine	8	8	3.5	12	11	12
Exhaust temperature of vent pipe (°C)	Propulsion Engine	255-260	210-230	n.a.	600	426	600
	Auxiliary Engine	n.a.	n.a.	148-156	350	315	350
Exhaust diameter of vent pipe (m)	Propulsion Engine	0.3	0.3	0.2	0.273	0.2	0.273
	Auxiliary Engine	0.15	0.15	0.1	0.14	0.2	0.14

Note

[1] From measurement of the IETS and IWTS vessels, average electricity consumption of 75 kWh is adopted (sourced from approved STF EIA)

[2] The design and taveling/berthing mode of the additional vessel for STF was assumed the same as WKTS vessels.

Marine Vessels Arrival/Departure Timetable

		HR 01	HR 02	HR 03	HR 04	HR 05	HR 06	HR 07	HR 08	HR 09	HR 10	HR 11	HR 12	HR 13	HR 14	HR 15	HR 16	HR 17	HR 18	HR 19	HR 20	HR 21	HR 22	HR 23	HR 24
IETS Vessles	Idling																								
	Maneuvering																								
	N/A																								
IWTS Vessles	Idling																								
	Maneuvering																								
	N/A																								
OITF Vessles	Idling																								
	Maneuvering																								
	N/A																								
NLTS Vessles	Idling																								
	Maneuvering																								
	N/A																								
WKTS Vessles	Idling																								
	Maneuvering																								
	N/A																								
STF Vessles	Idling																								
	Maneuvering																								
	N/A																								

Detailed Calculation of Emissions from Marine Vessels

Emission (g/hr) = Engine Power (kW) x Loading Factor x Emission Factor (g/kWh)

	Emission Factor	Adjusted Emission Factors using fuel with average 0.3% sulphur content
	(g/kWh)	(g/kWh)
NO_x	13.2	13.2
SO_2	0.63	0.126
RSP	0.72	0.144

IETS Vessels

	Operation Mode	Total Emission	Travel Distance	Travel Time	Emission Rate
		(g/s)	(m)	(min)	(g/s)
NO_x	During Maneuvering	2.4273	1984	10.71	1.057E-02
	During Iding	0.2750	-	-	2.750E-01
SO_2	During Maneuvering	0.0232	1984	10.71	1.009E-04
	During Iding	0.0026	-	-	2.625E-03
RSP	During Maneuvering	0.0265	1984	10.71	1.153E-04
	During Iding	0.0030	-	-	3.000E-03

IWTS Vessels

	Operation Mode	Total Emission	Travel Distance	Travel Time	Emission Rate
		(g/s)	(m)	(min)	(g/s)
NO_x	During Maneuvering	2.4273	1984	10.71	1.057E-02
	During Iding	0.2750	-	-	2.750E-01
SO_2	During Maneuvering	0.0232	1984	10.71	1.009E-04
	During Iding	0.0026	-	-	2.625E-03
RSP	During Maneuvering	0.0265	1984	10.71	1.153E-04
	During Iding	0.0030	-	-	3.000E-03

OITF Vessels

	Operation Mode	Total Emission	Travel Distance	Travel Time	Emission Rate
		(g/s)	(m)	(min)	(g/s)
NO_x	During Maneuvering	1.7783	1984	8.03	5.808E-03
	During Iding	0.2552	-	-	2.552E-01
SO_2	During Maneuvering	0.0170	1984	8.03	5.544E-05
	During Iding	0.0024	-	-	2.436E-03
RSP	During Maneuvering	0.0194	1984	8.03	6.336E-05
	During Iding	0.0028	-	-	2.784E-03

NLTS Vessels

	Operation Mode		Total Emission	Travel Distance	Travel Time	Emission Rate
			(g/s)	(m)	(min)	(g/s)
NO_x	During Maneuvering	Propulsion Engine	2.9333	1984	6.43	7.664E-03
		Auxiliary Engine	1.2362	1984	6.43	3.230E-03
	During Iding		1.2536	-	-	1.254E+00
SO_2	During Maneuvering	Propulsion Engine	0.0280	1984	6.43	7.316E-05
		Auxiliary Engine	0.0118	1984	6.43	3.083E-05
	During Iding		0.0120	-	-	1.197E-02
RSP	During Maneuvering	Propulsion Engine	0.0320	1984	6.43	8.361E-05
		Auxiliary Engine	0.0135	1984	6.43	3.524E-05
	During Iding		0.0137	-	-	1.368E-02

WKTS Vessels

	Operation Mode	Total Emission	Travel Distance	Travel Time	Emission Rate
		(g/s)	(m)	(min)	(g/s)
NO_x	During Maneuvering	6.5619	1984	8.03	2.143E-02
	During Iding	0.0000	-	-	0.000E+00
SO_2	During Maneuvering	0.0626	1984	8.03	2.046E-04
	During Iding	0.0000	-	-	0.000E+00
RSP	During Maneuvering	0.0716	1984	8.03	2.338E-04
	During Iding	0.0000	-	-	0.000E+00

STF Vessels

	Operation Mode	Total Emission	Travel Distance	Travel Time	Emission Rate
		(g/s)	(m)	(min)	(g/s)
NO_x	During Maneuvering	6.5619	1984	8.03	2.143E-02
	During Iding	0.0000	-	-	0.000E+00
SO_2	During Maneuvering	0.0626	1984	8.03	2.046E-04
	During Iding	0.0000	-	-	0.000E+00
RSP	During Maneuvering	0.0716	1984	8.03	2.338E-04
	During Iding	0.0000	-	-	0.000E+00