Sound Resource Management

February 18, 2010

Mr. Ted Rattray
President
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Suite 900
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Dear Mr. Rattray:

Presented herein are Sound Resource Management Group's best estimates of performance criteria for an in-region waste-to-energy (WTE) facility and an out-of-region landfill managing 500,000 tonnes per year (TPY) of municipal solid waste (MSW) generated in the Metro Vancouver region. Based on the life cycle analysis (LCA) for SRMG's recent report on the environmental impacts of waste management in Metro Vancouver, and updates to that LCA since then, Table 1 compares performance criteria for a WTE facility producing electricity for the BC grid and steam for district heating against a landfill facility producing liquefied natural gas (LNG) for use as a truck fuel such as the Cache Creek Landfill Extension.

Table 1
Annual Performance Criteria for Waste Management Facilities
Emissions / (Emissions Reductions) from 500,000 TPY MSW Disposal

Performance Criteria	In-Region Waste-to-Energy	Out-of-Region Landfill
NOx (tonnes)	2	16
SOx (tonnes)	93	(11)
PM10 (tonnes)	4	2
CO (tonnes)	(56)	9
VOCs (tonnes)	(31)	4
Ammonia (tonnes)	17.2	(0.1)
Mercury (kg)	34.4	0.1
Dioxins & Furans (mg TEQ)	15.3	1.5
GHGs (tonnes CO2e)	142,459	(127,462)

As indicated in Table 1, the out-of-region landfill out performs the in-region WTE for sulfur oxides (SOx), particulates (PM10), ammonia, mercury, dioxins/furans, and greenhouse gases (GHGs). Estimated emissions from landfill equipment result in the landfill emitting more nitrogen oxides (NOx). Estimated carbon monoxide (CO) emissions from flaring landfill gas not used in the LNG production process result in the landfill emitting more CO. Landfill equipment and fugitive landfill gas emissions account for the vast majority of landfill releases of volatile organic compounds (VOCs).

Sets of performance criteria for WTE versus landfill have also been estimated in LCAs prepared for Metro Vancouver by AECOM, Sheltair and others. Metro Vancouver has publicized one of these sets of performance criteria in recent presentations and circulated that set in a Waste Management FACT SHEET.

There are substantial differences between Metro Vancouver's publicized performance criteria and those in Table 1. The remainder of this letter report and the supporting documentation in the attached appendix discuss the following major reasons for these differences.

- Greenhouse gas (GHG) offsets from storage/sequestration of biogenic carbon in landfills are ignored in the Metro Vancouver performance criteria estimates, contrary to internationally accepted best practices for waste management LCA and GHG accounting.
- GHG and other environmental benefits from use of landfill methane to produce LNG are included in Table 1, whereas Metro Vancouver assumed that landfill methane will be burned in an internal combustion engine to generate electricity.
- Metro Vancouver may be over-estimating the capacity of local markets to absorb WTE steam/hot water for district heating and under-estimating the amount of energy lost in transporting steam/hot water from the WTE facility to steam/hot water purchasers. At a minimum Metro Vancouver should provide its assumptions in this regard.
- Fugitive methane oxidation as it flows to the surface of a landfill is ignored in the Metro Vancouver performance criteria estimates.
- In their performance criteria estimates Metro Vancouver included WTE stack emissions based on wet flue gas treatment (FGT); whereas typical emissions control systems in North America use semi-dry FGT technologies. If wet FGT is assumed, then appropriate and updated capital and operating costs should be provided by Metro Vancouver

1. <u>GHG Offsets from Sequestration of Biogenic Landfill Carbon Are Included</u>

Carbon in cellulosic and hemi cellulosic materials does not degrade completely under anaerobic conditions, as confirmed both by empirical tests and casual observations during excavations at landfills. The AECOM report's calculations for an out-of-region landfill excluded GHG offsets for biogenic carbon storage. This is an accounting error according to the IPCC. The IPCC's 4th Assessment Report states, "Because landfills function as relatively inefficient anaerobic digesters, significant long-term carbon storage occurs in landfills, which is addressed in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories."[1] Further, "Since lignin is recalcitrant and cellulosic fractions decompose slowly, a minimum of 50% of the organic carbon landfilled is not typically converted to biogas carbon but remains in the landfill… Carbon storage makes landfilling a more competitive alternative from a climate change perspective, especially where landfill gas recovery is combined with energy use."[2]

In addition, both the US EPA and Environment Canada calculators for determining GHG impacts of solid waste management options include biogenic carbon storage as an offset when computing the carbon footprint for landfill disposal.

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[1] Intergovernmental Panel on Climate Change, *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, New York, 2007, page 589. See Box 10.1 on pages 591-592 for estimates of landfill carbon storage in the various regions of the world.
[2] *Ibid*, page 601.

According to composition estimates for Metro Vancouver's disposed MSW[3], there are 0.7 tonnes of biogenic carbon dioxide equivalents (CO2e) in each tonne of MSW. According to US EPA estimates for the proportion of biogenic carbon storage/sequestration for each type of waste material landfilled[4], 59% of biogenic carbon is sequestered for each tonne landfilled. Disposal of 500,000 tonnes per year of MSW in a landfill, thus, provides a storage/sequestration benefit that reduces the carbon footprint of the landfill by 208,500 tonnes per year of carbon dioxide equivalents.

2. Higher GHG Offsets from Conversion of Landfill Methane into LNG vs. Electricity

Conversion of captured methane generated in a landfill into liquefied natural gas (LNG) provides a fuel that can be substituted for petroleum diesel. Because the methane is generated by decomposition of biogenic material, the CO2 emissions from using LNG as a truck fuel do not count as greenhouse gas (GHG) emissions. At the same time, the substitution of LNG for petroleum diesel displaces GHG emissions that would otherwise occur from using petroleum diesel for truck fuel. Taking into account the GHGs emitted from generating the BC grid electricity that is used in converting methane to LNG, the LNG truck fuel produced from 500,000 tonnes of MSW will reduce GHG emissions by 68,500 tonnes CO2e through displacement of petroleum diesel.[5]

Because BC Hydro has such a small carbon footprint for its electricity generation, the 68,500 tonne CO2e offset from landfill-methane-produced LNG is much larger than the offset that could be provided by using landfill methane to generate electricity.[6]

3. Lower Estimate of New WTE Facility Hot Water Sales

The Burnaby WTE facility sells 300,000 tonnes of steam each year, a portion of the energy generated from annual combustion of 275,000 tonnes of MSW. Assuming that a 500,000 tonne per year (TPY) WTE facility could be located so as to have access to proportionally scaled-up markets for steam/hot water energy, the new WTE facility would market 545,000 tonnes of steam/hot water. This is 1.8 times more steam energy than is currently marketed by the Burnaby WTE facility. These additional sales of steam/hot water energy would displace 99,000 tonnes CO2e that would otherwise be emitted annually from using natural gas.[7]

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[3] See Table A1 in Section 1 of the appendix.

[4] Exhibit 6-2 from EPA's 2006 report is reproduced following Table A1in Section 1 of the appendix.

[5] Disposal of 500,000 tonnes of MSW in one year in a landfill results in methane generation over a number of years following disposal. Furthermore, in arid areas such as Cache Creek the generation of methane is slower and continues for a longer time than in an area of high precipitation such as Vancouver. Landfills in both wet and dry areas eventually generate the same amount of methane given similar MSW disposal quantities and composition. The important point here is that in either wet or dry areas, the methane generated in any single subsequent year following disposal of 500,000 tonnes MSW will not produce enough LNG to displace an amount of petroleum diesel sufficient to reduce GHG emissions by 68,500 tonnes CO2e in that single year. However, over all the years following disposal of the 500,000 tonnes, enough methane will be generated in total to produce amounts of LNG that all together will reduce GHGs by 68,500 tonnes CO2e.

[6] Section 2 in the appendix provides further details on the LNG production parameters and a comparison with the CO2e displaced if captured landfill methane were to be used to generate electricity.

[7] Section 3 in the appendix provides details on energy loss in transporting steam/hot water to markets and energy efficiency for the displaced natural gas boilers and furnaces.

Based on the scaling-up assumption, steam/hot water energy sales and electricity generation at the new in-region WTE facility amount to use of output energy that equals 50% of the energy input from MSW combusted. This compares with the AECOM report's assumption that the new 500,000 TPY WTE facility (or facilities) can market 4.5 times more steam/hot water energy than is currently marketed by the Burnaby facility, thereby achieving an input-output energy efficiency of 90%, including electricity generation. The substantiation for this assumption has not been provided by AECOM or Metro Vancouver.

Little if anything has been revealed by Metro Vancouver about the nature, location or availability of additional steam/hot water energy markets; the energy losses from transporting steam/hot water to these purchasers; or the seasonality of these new steam/hot water energy markets. Even the 180% increase in steam/hot water energy sales assumed in the calculations for Table 1 seems highly speculative given the current paucity of information on the location and size of district heating systems in Metro Vancouver to which the new WTE facility's steam/hot water energy output could connect.

4. Less Fugitive Methane Due to Accounting for Methane Oxidation in the Landfill

US EPA states, regarding fugitive emissions of organic landfill gas (LFG) constituents (e.g., methane): "Some capture and subsequent microbial degradation of organic LFG constituents within the landfill's surface area may occur."[8] Further: "Average oxidation of methane (on a volumetric basis) in some laboratory and case studies on landfill covers have indicated ranges from 10 percent to over 25 percent with the lower portion of the range being found in clay soils and higher in topsoils."[9]

Following Kaplan et al (2009), the estimated methane oxidation rate in the landfill surface area used in calculations for Table 1 is 15%.[10] That is, 15% of the fugitive methane (the methane not captured by the landfill's gas capture system) is oxidized to CO2 before it reaches the atmosphere. Since landfill methane is generated by biogenic materials, this CO2 does not count as a GHG emission. Oxidized fugitive methane emissions in the 500,000 TPY landfill amount to 26,000 tonnes CO2e annually.

5. WTE Stack Emissions from Semi-Dry, Rather than Wet, Flue Gas Treatment (FGT)

Table 2 shows annual stack emissions from the WTE facility based on projections reported in the LCAs for Metro Vancouver prepared by Sheltair and AECOM. The Sheltair projections are based on current stack emissions at the Burnaby WTE, but updated by Sheltair to reflect performance expectations for a new WTE facility. The AECOM wet flue gas treatment (FGT) projections are based on the SYSAV WTE facility in Sweden, while the AECOM semi-dry FGT projections are based on a typical semi-dry system using selective catalytic reduction (SCR) controls for NOx. According to the

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[8] US EPA, *Background Information Document for Updating AP-42 Section 2.4 for Estimating Emissions from Municipal Solid Waste Landfills*, prepared by Eastern research Group for US EPA National Risk Management Research Laboratory (EPA Project Officer S. Thorneloe), EPA/600/R-08-116, Research Triangle Park, NC: September 2008, page 4.
[9] US EPA, *Direct Emissions from Municipal Solid Waste Landfilling*, Climate Leaders Greenhouse Gas Inventory Protocol, Core Module Guidance, EPA-430-K-04-011, Washington, DC: October 2004, page 14.
[10] Kaplan, P. O.; Decarolis, J.; Thorneloe, S. 2009. Is It Better To Burn or Bury Waste for Clean Electricity Generation? *Environmental Science & Technology*, 43(6), page 1712.

AECOM report (at page 123) the SYSAV facility emissions profile for wet FGT was used to estimate pollutant emissions from new WTE facilities in the AECOM LCA study's scenarios.

Due to the lack of experience in North America with wet FGT systems, as well as the very high likelihood that any new WTE facility actually would use semi-dry FGT with SCR, Table 1 performance criteria include WTE stack emissions based on the AECOM projections for typical semi-dry FGT systems for pollution control.[11]

Table 2
Performance Criteria for WTE Stack Emissions
(500,000 tonnes per year)

	WTE Stack Emissions in Metro LCAs		
	Sheltair	AECOM	
Performance Criteria	Updated Burnaby	Semi-Dry FGT	Wet FGT
NOx (tonnes)	150	173	69
SOx (tonnes)	71	106	10
PM10 (tonnes)	16	10	7
CO (tonnes)	52	35	35
VOCs (tonnes)	NA	2	2
Ammonia (tonnes)	NA	17	15
Mercury (kg)	16	35	22
Dioxins & Furans (mg TEQ)	15	25	1

Respectfully Submitted,

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[11] Section 5 in the appendix provides the tables from the AECOM and Sheltair LCAs which were used to calculate the emissions shown in Table 2.

Appendix

1. GHG Offsets from Sequestration of Biogenic Landfill Carbon Are Included

Table A1
Metro Vancouver Disposed Waste Composition and Characterization, 2008

	Metro Vancouver MSW Disposal Composition	Heating Value	Carbon Content	Carbon Content (MTeCO2/MT)		Landfill Methane (CH4) Generation Per Metric Ton		Landfill Biogenic Carbon Storage
				Fossil	Biogenic	L_0	CH4 Weight	
Paper & Paperboard	(%)	(MJ/kg)	(%)	(MTCO2e/MT)	(MTCO2e/MT)	(cubic meters)	(kilograms)	(MTeCO2/MT)
Newspaper	3.1%	16.5	46%	0.0	1.689	68	45	1.5
Corrugated	5.9	15.2	45	0.0	1.637	192	128	0.9
Mixed Paper	7.8	15.7	38	0.0	1.379	182	121	1.0
Bev Cont	0.3	14.9	43	0.2	1.310	154	102	0.7
Other	6.3	15.7	38	0.0	1.379	192	128	1.0
Plastics								
Film	5.1	31.9	66	2.4	0.000	0	0	0.0
Bev	0.4	45.5	62	2.3	0.000	0	0	0.0
Rigid	4.6	45.5	84	3.1	0.000	0	0	0.0
Textiles	2.2	22.8	62	2.3	0.000	0	0	0.0
Other	1.3	38.2	62	2.3	0.000	0	0	0.0
Organics (compostable)								
Yard	5.8	2.6	19	0.0	0.689	74	49	0.4
Food	22.5	1.4	15	0.0	0.561	124	83	0.1
Wood	5.1	15.8	42	0.0	1.527	99	66	1.3
Organics (non-compostable)								
Wood	4.0	15.8	42	0.0	1.527	99	66	1.3
Textiles	1.3	14.9	44	1.0	0.737	96	64	0.4
Leather	0.1	15.7	38	0.0	1.386	192	128	0.9
Rubber	0.4	22.8	76	1.4	1.401	0	0	1.3
Multiple/Composite	1.5	18.9	44	1.2	0.655	96	64	0.4
Metals								
Ferrous	2.2	0.7	5	0.0	0.183	0	0	0.0
Aluminum/Other Non-Ferrous	0.8	0.7	1	0.0	0.037	0	0	0.0
Other	0.5	0.7	1	0.0	0.037	0	0	0.0
Glass								
Bev	0.7	0.1	1	0.0	0.037	0	0	0.0
Food	0.9	0.1	1	0.0	0.037	0	0	0.0
Other	1.3	0.1	1	0.0	0.037	0	0	0.0
Inorganic Building Materials								
Gypsum	2.7	1.0	3	0.0	0.098	12	8	0.1
Masonry and Concrete	0.3	0.0	0	0.0	0.000	0	0	0.0
Rock/Dirt/Ceramic/Soil/Rubble	1.2	0.0	0	0.0	0.000	0	0	0.0
Rigid Asphalt Products	0.1	6.4	0	0.0	0.000	0	0	0.0
Carpet	2.4	22.8	46	1.7	0.000	0	0	0.0
Other (asphalt, etc.)	1.0	6.4	0	0.0	0.000	0	0	0.0
Electronic Waste	2.3	9.5	28	1.0	0.000	0	0	0.0
Household Hazardous	0.6	27.3	51	1.9	0.000	0	0	0.0
Household Hygiene	3.1	18.8	40	1.1	0.430	169	113	0.0
Bulky Objects								
White Goods	0.3	0.7	0	0.0	0.000	0	0	0.0
Upholstered	0.7	17.3	49	0.7	1.100	74	49	0.7
Other	0.8	7.7	24	0.0	0.000	96	64	0.0
Fines/Misc	0.6	6.4	24	0.0	0.862	96	64	0.0
Total/Average	100.0%	12.9	31.8	0.508	0.711	91	61	0.4

Sources:

Disposal Composition - Sound Resource Management, Environmental Life Cycle Assessment of Waste Management Strategies with a Zero Waste Objective: Study of the Solid Waste Management System in Metro Vancouver, British Columbia. Belkorp Environmental Services, Inc.: Vancouver BC, 2009.

Heating Value - P O Kaplan, J Decarolis and S Thornloe 2009, "Is It Better To Burn or Bury Waste for Clean Electricity Generation?" *Environmental Science & Technology*, 43(6) 1711-1717; P A Vesilind, W A Worrell, and D R Reinhart, *Solid Waste Engineering*. Brooks/Cole: Pacific Grove CA, 2002; J Morris 1996, "Recycling versus incineration: An energy conservation analysis". *Journal of Hazardous Materials,* 47(1-3) 277-293; and P A Vesilind and A E Rimer, *Unit Operations in Resource Recovery Engineering*. Prentice-Hall: Englewood Cliffs NJ, 1981.

Carbon Content - US EPA, *Solid Waste Management and Greenhouse Gases: A Life-Cycle Assessment of Emissions and Sinks, 3rd Edition*. US EPA: Washington, DC, 2006; Vesilind *et al* 2002, *op.cit*.; and Vesilind and Rimer 1981, *op. cit*.

Landfill Methane Generation - Kaplan *et al* 2009, *op.cit*., and US EPA 2006, *op.cit*.

Landfill Biogenic Carbon Storage - US EPA 2006, *op.cit*., and Vesilind *et al* 2002, *op. cit.*

The following exhibit table from US EPA, 2006, *op.cit.*, page 84, along with typical moisture content of MSW materials given in Vesilind *et al* 2002, *op. cit.*, provide the basis for the estimates of carbon storage shown in Table 1.

Exhibit 6-2
Experimental and Adjusted Values for CH_4 Yield and Carbon Storage.a

	Initial Carbon Content, % Of dry Matter **a**	**Measured Yield as a % Of Initial Carbon** **b**	**Implied Yield Of Biogas (CH_4+CO_2) as Proportion Of Initial Carbon** **c (=2×b)**	**Measured Proportion of Initial Carbon Stored** **d**	**Output as % of Initial Carbon** **e (=c+d)**	**Adjustment Approach** **f**	**Adjusted Yield of CH_4 as Proportion Of Initial Carbon** **g**	**Adjusted Proportion Of Initial Carbon Stored** **h**
Paper and Paperboard								
Corrugated	46%	16%	32%	55%	88%	inc biogas	*22%*	55%
Newsprint	49%	8%	15%	85%	100%	NA	8%	85%
Office Paper	40%	27%	54%	12%	66%	inc biogas	*44%*	12%
Coated Paper	34%	12%	25%	99%	124%	reduce LF C	12%	*75%*
Food Discards	50%	30%	59%	16%	75%	inc biogas	*42%*	16%
Yard Trimmings								
Grass	44%	16%	32%	71%	103%	reduce LF C	16%	*68%*
Leaves	41%	7%	14%	72%	86%	inc biogas	*14%*	72%
Branches	49%	6%	13%	77%	90%	inc biogas	*12%*	77%
MSW	42%	11%	22%	52%	74%	inc biogas	*24%*	52%

a CH_4 generation estimates are from Eleazer, et al. (1997), op cit. Carbon storage and initial carbon content values are from Barlaz (1998), op cit. All values for leaves (initial carbon content, CH_4 generation, and carbon storage) are from updated experiments reported in a letter report from M.A. Barlaz to J.R. Freed (of ICF Consulting) dated June 29, 2005.

2. <u>Higher GHG Offsets from Conversion of Landfill Methane into LNG vs. Electricity</u>

The following estimates were used to calculate GHG impacts from LNG production:

- 80 liters LNG produced from each tonne of MSW landfilled, given a 75% capture rate for generated methane.
- 80 liters of LNG production requires 78 kWh of electricity from the BC grid.
- BC grid electricity is generated from 90% renewable and 10% natural gas fuels.
- Electricity generated via natural gas combustion is from a combined cycle generator at 40% efficiency.
- Natural gas production and combustion releases almost 2.2 kg CO2e per cubic meter.
- Natural gas energy value is 38.4 MJ per cubic meter.
- At 40% efficiency and 3.6MJ for one kWh, a cubic meter of natural gas yields 4.3 kWh.
- At 90% renewable and 10% natural gas generation on the BC grid, one kWh from the BC grid causes emissions of 0.05 kg CO2e.
- 1.7 liters LNG displace 1 liter petroleum diesel for truck fuel.
- Petroleum diesel production and combustion releases 3 kg CO2e per liter.

From these parameters one can calculate that LNG from 500,000 tonnes of MSW displaces 70,500 tonnes of diesel CO2e. Production of the LNG from 500,000 tonnes requires 39 million kWh and results in 2,000 tonnes of CO2e emissions.
The net result of substituting landfill LNG for diesel truck fuel is displacement of 68,500 tonnes CO2e each year.

The Metro Vancouver Waste management FACT SHEET indicates that electricity production at an out-of-region landfill would be just 17.5% of electricity production at the WTE. At 530 net kWh per tonne generated at the WTE, this implies net electricity generation of just 93 kWh per tonne at the landfill, or 46 million kWh per year. The displacement of BC grid electricity would therefore reduce GHG emissions by less than 2,500 tonnes CO2e.

3. Lower Estimate of New WTE Facility Hot Water Sales

The following estimates and assumptions were used to calculate GHG impacts from steam/hot water sales:

- 3.2 GJ energy per tonne steam/hot water.
- 1.09 tonnes steam produced per tonne MSW.
- 10% heat energy lost in delivering the steam/hot water to location where purchaser uses it; so 2.9GJ energy available at purchaser's site to displace natural gas used in boilers or furnaces.
- Efficiency of natural gas fired boilers and furnaces is 90% on average.

From these parameters one can calculate that 2.9 GJ of steam/hot water energy displaces nearly 84 cubic meters of natural gas. This amounts to over 45 million cubic meters of natural gas displaced by 545,000 tonnes of steam/hot water sales at the WTE facility. At almost 2.2 kg CO2e emissions for production and combustion of one cubic meter of natural gas, annual CO2e emissions reductions amount to 99,000 tonnes CO2e.

4. Less Fugitive Methane Due to Accounting for Methane Oxidation in the Landfill

The following estimates were used to calculate the GHG impacts of oxidation of fugitive CH4 emissions:

- 25% of methane released over a 100 year time frame is not captured by the landfill's LFG collection system.
- The landfill is in an arid region and so the rate of landfill gas generation is low, which implies that only 91% of the potential generation of methane occurs within the 100 years following MSW burial in the landfill.
- Fugitive methane is oxidized at a 15% rate before reaching the landfill's surface and being emitted to the atmosphere.
- Table A1 indicates that 61 kg of methane are generated from each tonne of landfilled MSW.

Thus, oxidized fugitive emissions of methane from one tonne of MSW amount to 61*.91*.25*.15 = 2.1 kg CH4. According to the IPCC's 4^{th} Assessment Report, over a 100 year time period methane has a global warming potential 25 times greater than CO2. Thus, the oxidation of fugitive methane before it reaches the landfill surface and is emitted to the atmosphere amounts to 52kg of CO2e. For 500,000 tonnes of MSW, fugitive methane oxidation at a 15% rate reduces GHG emissions from the landfill by 26,000 tonnes CO2e.

5. WTE Stack Emissions from Semi-Dry, Rather than Wet, Flue Gas Treatment (FGT)

Table 4-1: Inputs and Outputs for Modeled WTEF Process

	Metro Vancouver WTEF Annual basis (units / year)		**LCA Modeled Scenario** Direct "Scale-up" based on MSW throughput (units / year)		Modeled Flow *if different* from scale-up (units / year)		**Notes**
Inputs							
Waste Handled	**275,000**	tonne	**750,000**	tonne			
Activated Carbon	50	tonne	136	tonne			a
Lime	3,000	tonne	8,182	tonne			a
Ammonia	500	tonne	1,364	tonne			a
Phosphoric Acid	725	tonne	1,977	tonne			a
Municipal Water	200,000	m^3	545,455	m^3			a
Electricity	20,000	MWh	54,545	MWh	60750	MWh	l
Natural Gas	12,369	GJ	33,734	GJ			a
Outputs							
Steam Generation	907,500	tonne	2,475,000	tonne			a,d
Steam Sales	300,000	tonne	818,182	tonne	300,000	tonne	a,b,c
Electricity	118,000	MWh	321,818	MWh	458,380	MWh	b, l
Bottom Ash	47,502	tonne	129,551	tonne			a
Fly Ash	10,026	tonne	27,344	tonne			a
Ferrous Metals	9,221	tonne	25,148	tonne			a
Emissions							
GHGs (CO2e)	-	-	-	-	292,500	tonne	m
Particulate Matter	8.6	tonne	23	tonne			
SO2	100.9	tonne	275	tonne	106	tonne	h
HCl	39.5	tonne	108	tonne	22	tonne	i
NOX	**435.8**	tonne	1,189	tonne	225	tonne	j
CO	**28.7**	tonne	78	tonne			
Class 1 metals	**0.010**	**tonne**	**0.027**	**tonne**			e
Cd	1.16	kg	3.16	kg			f, g
Hg	8.81	kg	24.0	kg			f, g
Ti	0.034	kg	0.09	kg			f, g
Class 2 metals	**0.04**	**tonne**	**0.109**	**tonne**			e
As	3.060	kg	8.35	kg			f, g
Co	1.052	kg	2.87	kg			f, g
Ni	35.9	kg	97.9	kg			f, g
Se	0.000	kg	0.00	kg			f, g
Te	0.000	kg	0.00	kg			f, g
Class 3 metals	**0.07**	**tonne**	**0.191**	**tonne**			e
Sb	2.121	kg	5.78	kg			f, g
Pb	10.799	kg	29.45	kg			f, g
Cr	5.689	kg	15.52	kg			f, g
Cu	3.778	kg	10.30	kg			f, g
Mn	3.076	kg	8.39	kg			f, g
V	0.192	kg	0.52	kg			f, g
Zn	44.344	kg	120.9	kg			f, g
Indentified Organics							
PCDD/PCDF	0.0082	g	0.0224	g			
PAHs	0.709	kg	1.934	kg			k

See notes next page

Notes to Table 4-1:

(a) Assumes that this parameter scales linearly with the volume of solid waste produced.

(b) Steam sales were assumed to be the same in the modeled WTEF as the existing Metro Vancouver WTEF. Additional steam generated is used to make electricity (at the same intensity per tonne as the existing facility). In practice, the amount of steam sold and the amount used to generate electricity would depend on site-specific features such as available buyers for the steam.

(c) Exported steam quality is assumed 13 bar and 260 degrees Celsius (i.e. superheated).

(d) Total steam generation is 3.3 tonnes per t_{MSW}.

(e) Metals emissions are stack emissions only and do not include the metals contained in the ash streams.

(f) Metals split within each Class is based on average of the test data for 2005.

(g) Display may include more significant digits than the original data may justify.

(h) SOx emissions per tonne of MSW are based on existing facility emissions prorated by the concentration ration of [stack emissions of a new WTEF (approx 25 mg/m^3)] to [stack emissions of the existing Metro Vancouver WTEF (65 mg/m^3)].

(i) HCl emissions per tonne of MSW prorated by concentration ratio of a new WTEF (<10 average 5 mg/m^3) to existing Metro Vancouver WTEF (approx 25 mg/m^3).

(j) NOx emissions per tonne of MSW are based on existing facility emissions prorated by the concentration ratio of [stack emissions of a new WTEF (approx 55 mg/m^3)] to [stack emissions of the existing Metro Vancouver WTEF (290 mg/m^3)]. This assumes flue gas recycling with SNCR technology.

(k) PAH data is from 2003 and does not define individual PAH.

(l) Based on comment from R. Anderson of Montenay, indicating that a new WTEF would likely use a higher pressure boiler system.

(m) Based on fossil component of the waste only - estimated as 40% of the carbon in the MSW (IPCC 2006). GHG estimates for the existing facility (as would be prepared by Metro Vancouver Air Quality Division) were not available for this work.

The emissions shown for the updated Burnaby WTE in Table 2 in the memorandum are calculated from Table 4-1, page 28 in Sheltair Group, *Environmental Life Cycle Assessment of Solid Waste Management: Evaluation of Two Waste Disposal Scenarios for the Metro Vancouver Region*; prepared for Metro Vancouver, Sheltair Group: Vancouver, February 2008. This table is reproduced above. The emissions shown in the Sheltair Table 4-1 for the 750,000 tonne modeled WTEF are scaled down proportionally to yield the emissions for the 500,000 tonne WTE shown in Table 2.

Mass flows of pollutants

Plant data	Unit*	Highly efficient wet FGT-plant	Semi-dry FGT, annual average
Waste throughput	metric ton/h	25	25
Lower heating value	MJ/kg	12	12
Flue gas flow rate, dry flue gas 11% O2, standard temperature and pres.	m^3/h	175.000	175.000
Operating hours	hours/y	8.100	8.100
Pollutant mass flows			
Carbone monoxide (CO)	kg/year	14.000	14.000
Nitrogen oxides (NOx)	kg/year	28.000	70.000/210.000**
Dust	kg/year	3.000	4.000
Total organic carbon (TOC)	kg/year	1.000	1.000
Sulphur dioxide (SO_2)	kg/year	4.000	43.000
Hydrogen chloride (HCl)	kg/year	3.000	11.000
Hydrogen fluoride (HF)	kg/year	< 1.000	< 1.000
Ammonia (NH_3)	kg/year	6.000	7.000/21.000**
Nitrous oxide (N_2O)	kg/year	< 7.000	< 7.000
Mercury (Hg)	kg/year	9	14
Cadmium + Tallium (Cd+Tl)	kg/year	0,3	14
Other heavy metals	kg/year	70	140
Dioxins (TCCD-ekv)	mg/year	0,3	10

**: SCR and SNCR, respectively

Table 10. Mass flow data for an EFW facility equipped with a FGT system with lowest possible emission values compared with semi-dry FGT system.

Table 10 above is reproduced here from AECOM Canada Ltd. *Management of Municipal Solid Waste in Metro Vancouver – A Comparative Analysis of Options for Management of Waste After Recycling*; prepared for Metro Vancouver, AECOM: Burnaby, BC, June 2009. Table 10 is in Appendix A of the AECOM report in Section 3, Flue gas emissions – lowest. The emissions shown in Table 10 in Appendix A of the AECOM report are annual amounts for a 202,500 TPY facility according to the waste throughput and annual operating hours entries shown in that table. The emissions shown in Table 2 in the memorandum here are scaled up proportionally to 500,000 tonnes of throughput.