



Durham/York Residual Waste Study

Annex E-3:

Supporting Technical Document on Electrical Energy Balances

Report on Selection of Preferred Residuals Processing System

May 30, 2006





Durham/York Residual Waste Study

Annex E-3: Supporting Technical Document on Electrical Energy Balances

Report on

Selection of Preferred Residuals Processing System

May 30, 2006

prepared by:



MacViro Consultants Inc.
600 Cochrane Drive, Suite 500
Markham, Ontario, Canada
L3R 5K3



Jacques Whitford Limited
461 North Service Road West, Unit B37
Oakville, Ontario, Canada
L6M 2V5

Table of Contents

1. Mechanical and Biological Treatment	3
1.1 System 1 Mechanical Biological Treatment (MBT) with Biogas Recovery	3
2. Thermal Treatment	4
2.1 System 2a) Thermal Treatment of Mixed Waste with Recovery of Materials from Ash/Char ..	4
2.2 System 2b) Thermal Treatment of Solid Recovered Fuel	5
2.3 System 2c) Thermal Treatment of Solid Recovered Fuel with Biogas Recovery	6

List of Figures

Figure 1 – Household Energy Usage Equivalence	2
---	---

List of Tables

Table 1 – Summary of Annual Electrical Energy Balance for Minimum Material Quantities (250,000 TPY)	1
Table 2 – Summary of Annual Electrical Energy Balance for Maximum Material Quantities (400,000 TPY)	2
Table 3 – System 1 Parasitic Loads	4
Table 4 – System 2c Parasitic Loads	7

Appendices

Appendix A Household Energy Equivalency	
---	--

Annex E-3: Electrical Energy Balances

Annex E-3 provides the electrical energy balances associated with the four (4) Durham/York Residual Waste Study residuals processing systems. These estimates include the gross electricity produced by each alternative (for those alternatives that produce electricity), the electrical energy consumed within the facilities (i.e., the plant parasitic consumption) and the electrical energy available to be sold. These estimates also distinguish between the electricity generated from all sources and the electrical energy generated solely from renewable energy sources within the waste stream. It is assumed that an electrical interconnection between the facility and the grid can readily be provided. Portions of this report are based on information and methodologies developed by the Niagara-Hamilton WastePlan Study.

It may be possible to also produce and sell steam or hot water as well as electricity (i.e., cogeneration). This approach requires that the facility be located in close proximity to an acceptable heat/steam load. As such a load may not be available, the overall analysis of the alternatives conservatively assumes that only electricity is sold and utilized outside the facility.

The analysis presented in this Annex utilizes the material quantity estimates provided in Annex E-1. The information presented in this Annex deals only with the energy generated and consumed within the facility. The information presented in Annex E-6 provides a broader life cycle perspective on the energy implications associated with each of the system alternatives.

The four (4) Durham/York Residual Waste Study System Alternatives are:

- 1 – Mechanical and Biological Treatment with Biogas Recovery
- 2a – Thermal Treatment of Mixed Waste with Recovery of Materials from the Ash/Char
- 2b – Thermal Treatment of Solid Recovered Fuel
- 2c – Thermal Treatment of Solid Recovered Fuel with Biogas Recovery

The electrical energy balances associated with the four system alternatives are summarized below. These energy balances are expressed in terms of megawatt hours (MWh) and gigajoules (GJ).

Table 1 – Summary of Annual Electrical Energy Balance for Minimum Material Quantities (250,000 TPY)

System Alternative	1	2a	2b	2c
Energy Balance in MWh				
Gross Electrical Energy Production	20,900	175,100	193,200	152,000
Gross Electrical Energy Production from Renewables	20,900	100,200	112,700	80,900
Plant Parasitic Consumption	10,600	24,500	46,400	37,500
Net Electrical Energy Sold	10,300	150,600	146,800	114,500
Net Renewable Electrical Energy Sold	10,300	86,200	85,700	56,800
Energy Balance in GJ				
Gross Electrical Energy Production	75,200	630,400	695,500	547,200
Gross Electrical Energy Production from Renewables	75,200	360,700	405,700	291,200
Plant Parasitic Consumption	38,200	88,200	167,000	135,000
Net Electrical Energy Sold	37,100	542,200	528,500	412,200

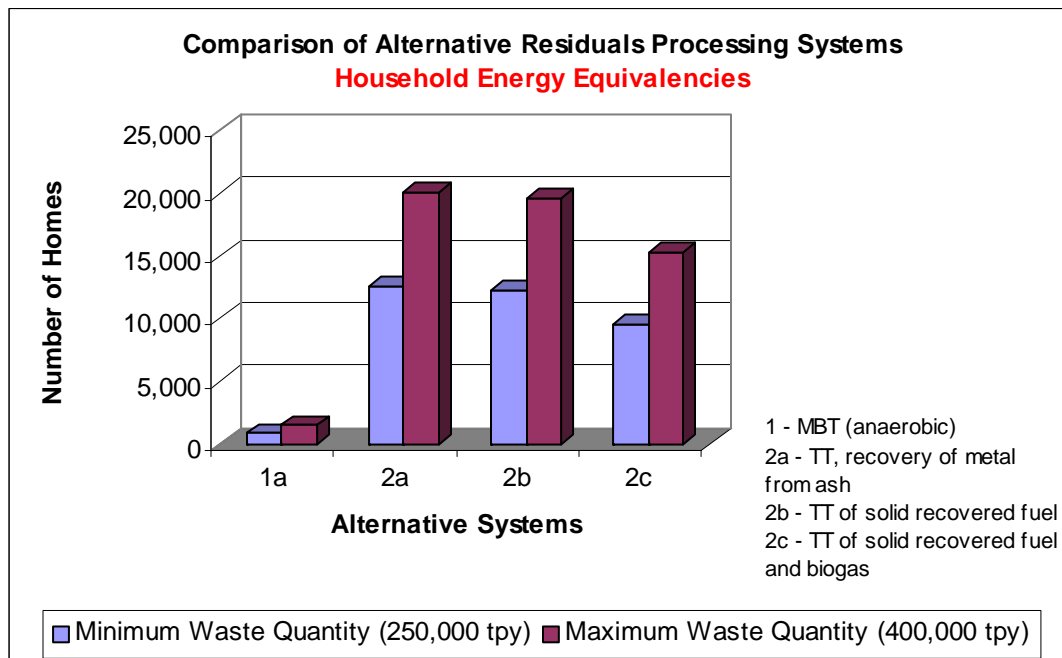
Net Renewable Electrical Energy Sold	37,100	310,300	308,500	204,500
--------------------------------------	--------	---------	---------	---------

Table 2 – Summary of Annual Electrical Energy Balance for Maximum Material Quantities (400,000 TPY)

System Alternative	1	2a	2b	2c
Energy Balance in MWh				
Gross Electrical Energy Production	33,500	280,100	309,100	243,100
Gross Electrical Energy Production from Renewables	33,500	160,300	180,400	129,400
Plant Parasitic Consumption	16,000	39,200	74,200	59,300
Net Electrical Energy Sold	17,500	240,900	234,900	183,800
Net Renewable Electrical Energy Sold	17,500	137,900	137,100	91,500
Energy Balance in GJ				
Gross Electrical Energy Production	120,600	1,008,400	1,112,800	875,200
Gross Electrical Energy Production from Renewables	120,600	577,100	649,400	465,800
Plant Parasitic Consumption	57,600	141,100	267,100	213,500
Net Electrical Energy Sold	63,000	867,200	845,600	661,700
Net Renewable Electrical Energy Sold	63,000	496,400	493,600	329,400

The following graph illustrates the net electrical output sold under each of the system alternatives. To put this energy output into perspective, the graph illustrates the net output in terms of the electrical consumption of a number of typical homes assuming a typical house consumes 12 MWh of electricity annually.

Figure 1 – Household Energy Usage Equivalence



The assumptions and basis for these estimates are detailed below.

Appendix A shows the spreadsheets in which the above numbers were calculated. Each spreadsheet shows the waste composition and energy balance for the particular system. The

thermal treatment alternatives have an “Energy Value” column in each of the spreadsheets which is based on measured waste fuel energy values¹.

1. Mechanical and Biological Treatment

1.1 System 1 Mechanical Biological Treatment (MBT) with Biogas Recovery

In this system, incoming post diversion waste is assumed to be received on a tipping floor and materials that are unacceptable for mechanical processing (e.g., mattresses) are removed. Some of these unacceptable materials such as large metal parts may be set aside for recycling, but most of the materials are assumed to be sent directly to landfill disposal.

The balance of the post diversion waste stream is assumed to be processed – mechanically treated - to remove recyclables, primarily metal and plastic containers. A relatively small quantity of these recyclable materials remain in the post diversion waste as the vast majority of these materials are assumed to be recovered through at-source diversion programs (e.g., blue box recycling). Mechanical treatment separates the waste stream into a number of fractions, from which some recyclables are removed. A large portion of the material is sent to landfill after removal of recyclables. A portion of the material is sent to biological treatment.

The portion of the remaining material stream that contains the highest percentage of organic materials (heavy, fines) is biologically treated via anaerobic digestion (AD) to breakdown organic materials. This process converts carbon-containing compounds to biogas (primarily methane and carbon dioxide), which in turn can be used to produce energy for in-plant consumption and sold to external users.

The residual materials, including stabilized organic material – digestate from the AD process – are assumed to be landfilled.

The gas production from the anaerobic digester was calculated assuming a gas production rate of 110 m³ of biogas with a 55% methane composition, per tonne of input material. These numbers are based on production rates from actual AD plant operation. As a result, the quantity of methane is determined by: input quantity (tonnes) x 110 m³ gas/tonne material x 55 % methane.

The energy value of the gas is determined using the lower heating value of natural gas, 34.3 MJ/m³. The total gas energy value was then converted to kWh by dividing by 3.6 (3.6 MJ = 1 kWh).

This methane is combusted in a reciprocating engine to produce electricity and heat. The engine used for this modeling was a 1,060 kW Jenbacher engine (JMS 320 GS –B.L.), which is made by GE and specializes in biogas. This engine has a full load electrical efficiency of 39% and a thermal efficiency of 46%. From these efficiencies, the potential thermal and electrical outputs were calculated. The Gross Electrical Output was found to be 20,913 MWh (225 kWh/tonne).

The system includes both mechanical and biological parasitic loads, which are summarized as follows:

Table 3 – System 1 Parasitic Loads

Parasitic Electrical Load	Mass Quantity (TPY) ¹	Calculation
Minimum Waste Quantities		
Mechanical	250,000 ²	2300kW connected x 50% load factor x 4000hrs = 16,560GJ
Biological	95,000	2000kW connected x 50% load factor x 6000hrs = 21,600GJ
TOTAL Parasitic		38,160GJ (Divide by 3.6 to get 10,600MWh or 10,600,000kWh)
Maximum Waste Quantities		
Mechanical	400,000 ²	3500kW connected x 50% load factor x 4000hrs = 25,200GJ
Biological	150,000	3000kW connected x 50% load factor x 6000hrs = 32,400GJ
TOTAL Parasitic		57,600GJ (Divide by 3.6 to get 16,000MWh or 16,000,000kWh)

¹ The mass quantity numbers are rounded from those used in the actual calculations.

² The quantities undergoing mechanical treatment include both the unacceptable waste removal at the front end of the system, and the tonnes to MT.

The net annual electrical output is 10,300 MWh for the minimum waste quantity or 17,500 MWh for the maximum waste quantity. All of the electrical energy output and thus all of the net electrical energy output is derived from the anaerobic digestion of renewable materials. Therefore, the power output is a renewable power stream.

2. Thermal Treatment

2.1 System 2a) Thermal Treatment of Mixed Waste with Recovery of Materials from Ash/Char

There are two main types of commercially available thermal treatment technologies: combustion and gasification. Depending on the technology, incoming waste may be received on either a flat tipping floor or into a receiving pit. The waste is inspected and any unacceptable items are removed.

In combustion technologies, hydrocarbons in the waste stream are converted to thermal energy, carbon dioxide, and water. Ash is discharged from the bottom of the grate and is quenched. Exhaust gases from combustion are cleaned prior to being emitted to the atmosphere. The process is exothermic (i.e., requires little to no external energy once combustion has been initiated).

Gasification technologies involve the thermal breakdown of solid materials into a synthetic gas (syngas) and a solid char residue. The process is endothermic (i.e., requires external energy). The syngas (mainly comprised of hydrogen, carbon monoxide, carbon dioxide, and nitrogen) must undergo a cleaning process before it is utilized. After cleaning, the syngas may be used as fuel for reciprocating engines or gas turbines, or it can be combusted in a steam boiler to generate steam.

After thermal treatment, mechanical treatment is utilized to recover metals (aluminum and ferrous) from the ash or char.

The residual materials, including materials unacceptable for thermal processing and ash or char, are assumed to be landfilled. In addition, residue from the flue gas or syngas cleanup process also requires management.

Using the energy values for each waste group, the overall energy value for the entire waste composition was calculated. The average material energy value was calculated by dividing the total energy content by the total material mass. In this case, it was found to be about 12.1 MJ/kg (5,200 BTU/lb).

The Thermal Processing is assumed to take place in an incinerator using a simple steam generator and steam turbine configuration. Today's large mass burn systems can reach approximately 30% electrical efficiency with a quality fuel stream. Smaller facilities, however, are only approximately 15 % efficient. Due to the difficulty of estimating the efficiency of the process, we turned to statistics from a report on municipal waste combustion in the United States². This report showed that a mass burn facility delivers, on average, 600 kWh net/tonne of input material, with a parasitic load of approximately 14%. Given the waste stream input, the gross efficiency of the system was calculated to be 21.5%, with a net efficiency of 18.5%.

System 2a was found to have a net electric output of 150,600 MWh (602 kWh/tonne) for the minimum waste input, and 240,900 MWh for the maximum waste input.

A portion of the gross and net electrical energy is derived from the combustion of renewable materials. Renewables are assumed to include the total fibre, organics, wood, textiles, building renovations, 30% of the bulky goods, and 50% of the miscellaneous goods in each process. This yields the estimate that about 64% of the residual waste stream is renewable. Applying this percentage yields the net electrical energy from renewables: 86,200 MWh for the minimum waste input and 137,900 MWh for the maximum waste input.

2.2 System 2b) Thermal Treatment of Solid Recovered Fuel

This system combines mechanical, biological (aerobic), and thermal treatment.

After removal of some unacceptable materials (similar to 2a) the incoming post diversion waste is processed and a portion of the material is separated into "large, dry, light" streams of plastic and paper materials. The other portion of the material includes more "small, wet, heavy" material including food waste residue, which is sent to biological treatment (aerobic composting) for bio-drying.

The waste is then processed mechanically to remove non-combustible materials and to recover some recyclable resources. A solid fuel is recovered and is fed into the thermal process to produce energy.

As mentioned under System 2a, the main thermal technologies are combustion or gasification. Combustion is an exothermic reaction in which hydrocarbons in the waste stream are converted to thermal energy, carbon dioxide, and water. The exhaust gases are cleaned prior to release into the atmosphere and the ash is discharged and quenched. Gasification is an endothermic reaction in which solid material is thermally broken down into syngas and a solid char residue. The syngas is cleaned before it is utilized for the generation of energy.

The materials requiring landfill disposal include the residuals from the recovery of solid fuel, the unacceptable waste and the ash/char from the thermal treatment. In addition, residue from the flue gas or syngas cleanup process also requires management.

The Bio-Drying process will increase the energy value of some materials as it evaporates moisture. The energy content values were derived from a combination of the dry and “as collected” material energy content¹.

Using the energy values for each waste group, the overall energy value for the entire waste composition can be calculated. The average material energy value can be calculated by dividing the total energy content by the total material mass. In this case, it was found to be 16.5 MJ/kg (7,100 BTU/lb).

This system involves preparation and combustion of Solid Recovered Fuel (SRF) and therefore will have different parasitic and gross energy yields than System 2a. To calculate the efficiency of the process, we again used statistics from a report on municipal waste combustion in the United States². This report showed that Refuse Derived Fuel (RDF) facility has a parasitic load of approximately 24%. Given the waste stream input, the gross efficiency of the system was calculated to be 30%, with a net efficiency of about 23%.

System 2b was found to have a net electric output of 146,800 MWh for the minimum system (540 kWh/tonne) and 234,900 MWh for the maximum system.

A portion of the gross and net electrical energy is derived from the combustion of renewable materials. Renewables are assumed to include the total fibre, organics, wood, textiles, building renovations, 30% of the bulky goods, and 50% of the miscellaneous goods in each process. This yields the estimate that about 64% of the solid recovered fuel is renewable. Applying this percentage yields the net electricity from renewables: 85,700 MWh for the minimum waste input and 137,100 MWh for the maximum waste input.

2.3 System 2c) Thermal Treatment of Solid Recovered Fuel with Biogas Recovery

This system is a variation of System 2b that involves the separation of the organic material (e.g., food waste) from the rest of the post diversion waste and the subsequent anaerobic digestion of this organic fraction of the waste stream to produce biogas. Energy is thus produced from both the solid recovered fuel and the biogas.

The residuals from anaerobic digestion, ash/char from the thermal treatment process and the residues from the mechanical treatment process all require landfilling. A small amount of waste from the air pollution control/gas clean-up system also requires management.

Using the energy values for each waste group, the overall energy value for the entire waste composition was calculated. The average material energy value was calculated by dividing the total energy content by the total material mass. In this case, it was found to be 18.2 MJ/kg (7,811 BTU/lb). This was then converted to MWh using the conversion factor of 3600 MJ/MWh.

The gas production from the anaerobic digester was calculated assuming a gas production rate of 110 m³/tonne of biogas with a 55% methane composition. These numbers are based on production rates from actual AD plant operation. As a result, the quantity of methane is determined by: input quantity (tonnes) x 110 m³ gas/tonne material x 55 % methane. The energy value of the gas is determined using the lower heating value of natural gas, 34.3 MJ/m³ (the

higher heating value being 37 MJ/m³ – a 10% increase). The total gas energy value was then converted to kWh by dividing by 3.6 (3.6 MJ = 1 kWh).

The system includes both mechanical and biological parasitic loads, which are summarized as follows:

Table 4 – System 2c Parasitic Loads

Parasitic Electrical Load	Mass Quantity (TPY) ¹	Calculation
Minimum Waste Quantities		
Biological	95,000	2000kW connected x 50% load factor x 6000hrs = 6,000 MWh
Maximum Waste Quantities		
Biological	150,000	3000kW connected x 50% load factor x 6000 hrs = 9,000 MWh

¹ The mass quantity numbers are rounded from those used in the actual calculations.

³ There is an additional thermal and mechanical parasitic load which is embedded in the overall thermal parasitic load allowance of 24%.

The Thermal Processing is assumed to take place in an incinerator similar to that described in System 2b and as such, the same gross efficiency and parasitic load (24%) was used for waste input to the thermal treatment process.

The parasitic load was subtracted from the net efficiency and System 2c was found to have a net electric output of 114,500 MWh for the minimum system (458 kWh/tonne) and 183,800 MWh for the maximum system.

A portion of the gross and net electrical energy is derived from the combustion of renewable materials. Renewables are assumed to include the total fibre, organics, wood, textiles, building renovations, 30% of the bulky goods, and 50% of the miscellaneous goods in each process. This yields the estimate that about 64% of the solid recovered fuel is renewable. Applying this percentage yields the net electricity from biological and thermal treatment of renewables: 56,800 MWh for the minimum waste input and 91,500 MWh for the maximum waste input.

References

1. Tchobanoglous, Theisen, Vigil, *Integrated Solid Waste Management*. Irwin McGraw-Hill: Boston, 1993. p80. Table 4.2.
2. Berenyi, Eileen B., *2005 – 2006 Municipal Waste Combustion in the United States: Yearbook and Directory*, 8th Edition, Government Advisory Associated, Inc., 2006. p. 39.

Appendix A

Household Energy Equivalency

Annex E-3
Appendix A - Household Energy Equivalencies

Assumptions

Average Household Annual Energy Consumption 12 MWh

	1a	2a	2b	2c
Minimum Net Electrical (MWh)	10,313	150,569	146,807	114,506
Maximum Net Electrical (MWh)	17,461	240,911	234,892	183,810
Minimum Net Households (# Households)	859	12,547	12,234	9,542
Maximum Net Households (# Households)	1,455	20,076	19,574	15,318

