IEA Bioenergy

Task 38

Greenhouse Gas Balances of Biomass and Bioenergy Systems

Greenhouse Gas Benefits

of using municipal solid waste as a fuel in a thermal treatment plant in Ireland

Summary

In this study the greenhouse gas (GHG) benefits of generating energy from the thermal treatment of municipal solid waste (MSW) was compared with two landfill scenarios; 1) with minimal gas flaring, 2) with gas recovery for electricity production. The lifecycle analysis encompassed GHG emissions and removals from transport, processing, disposal/use of by-products, and displaced emissions for a 30 year design life, equivalent to the disposal of 6 million tonnes of MSW.

The results listed in Table 1 indicate that thermal treatment with electricity recovery results in a small net reduction of 0.06 t CO_2e/t waste in terms of atmospheric GHG emissions. If demand for heat from thermal treatment could be found the GHG benefit would increase considerably to a reduction of 0.46 t CO_2e/t waste. Both landfill scenarios resulted in the net emission of GHG to the atmosphere of 0.85 and 0.09 t CO_2e/t waste for scenarios 1 and 2 respectively.

The key assumptions that influenced the results were associated with waste composition. This affected the subsequent calorific value and the methane generation parameters. Gas extraction efficiency in the landfill scenarios also significantly affected the results. Uncertainty estimates for waste thermal treatment and landfill gas flaring scenarios were relatively low (11 % and 10 % respectively) compared to the landfill gas recovery and electricity production scenario (approximately 42 %).

Should Ireland meet its thermal treatment capacity as outlined by the Integrated Waste Management Plan a GHG reduction potential could be created equivalent to 180,000 t CO_2e per year. If the full combined heat and power (CHP) potential of these operations could be realised, the GHG reduction potential could be increased to 920,000 t CO_2e per year.

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Scope

The primary focus of this study was to quantify the GHG impact through a lifecycle analysis of a proposed waste thermal treatment (WTT) plant with energy recovery at Carronstown, Co. Meath, Ireland.

The study compared the GHG balance with two landfill reference systems;

L1 – Limited gas collection, typical of the majority of existing landfills in Ireland. Gas collection occurs at the site periphery with an efficiency of 20 % and is subsequently flared with no energy recovery. The oxidation rate of the remaining CH_4 is assumed to be 10 % (Penman et al, 2000).

L2 – Best practice in accordance with the EU Landfill Directive. Gas collection efficiency is assumed at 70 % and as with L1 the oxidation rate of the remaining CH_4 is 10 %. Of the collected gas, 60 % is used for energy production (with an energy conversion efficiency of 30 %) and the remaining 40 % of the collected gas is flared.

Estimates of the atmospheric GHG impact of each scenario over a 30 year design life resulting in the disposal / treatment of 6 million tonnes of MSW, were developed within a system boundary (Figure 1) encompassing four process areas;

- Transportation of the waste and any by-products arising from the treatment
- Direct emissions and energy used in the waste treatment process including any onsite operations
- Influences on atmospheric GHG through the disposal or use of by-products including any materials recycled or materials sequestered in landfill
- Displaced emissions from energy recovered where that energy would have been generated by fossil fuels

The study considered emissions from construction and decommissioning of waste treatment facilities to be insignificant compared with the operation of the facilities (Smith et al, 2001) and were not included.

Methodology

Transportation

The transportation of waste to each facility was considered the same, calculated based on truck distances travelled (Indaver Ireland, 2005) and typical CO_2 emissions expected from each vehicle (Smith et al, 2001). Nitrous oxide emissions were estimated as 1 % of the CO_2 emitted (Winiwarter et al, 2001).

Daily operational transport requirements for the WTT are expected to be 4 trucks per day (Indaver Ireland, 2005) taking a round trip of 80 km. This included sourcing operational materials and removal of non-hazardous waste.

On-site emissions from spreading and compaction were 0.001 t CO_2 / t MSW.

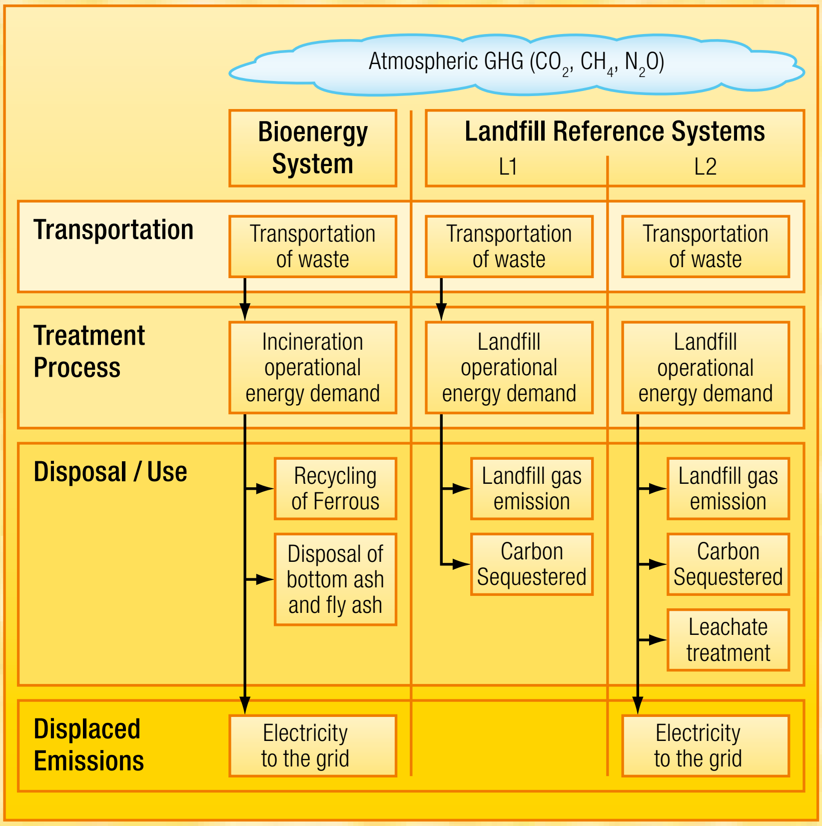


Figure 1: Lifecycle system boundary of the bioenergy system and the two landfill reference systems. The carbon sequestered in landfill contains both fossil (plastics) and biogenic carbon (wood, boards, paper etc).

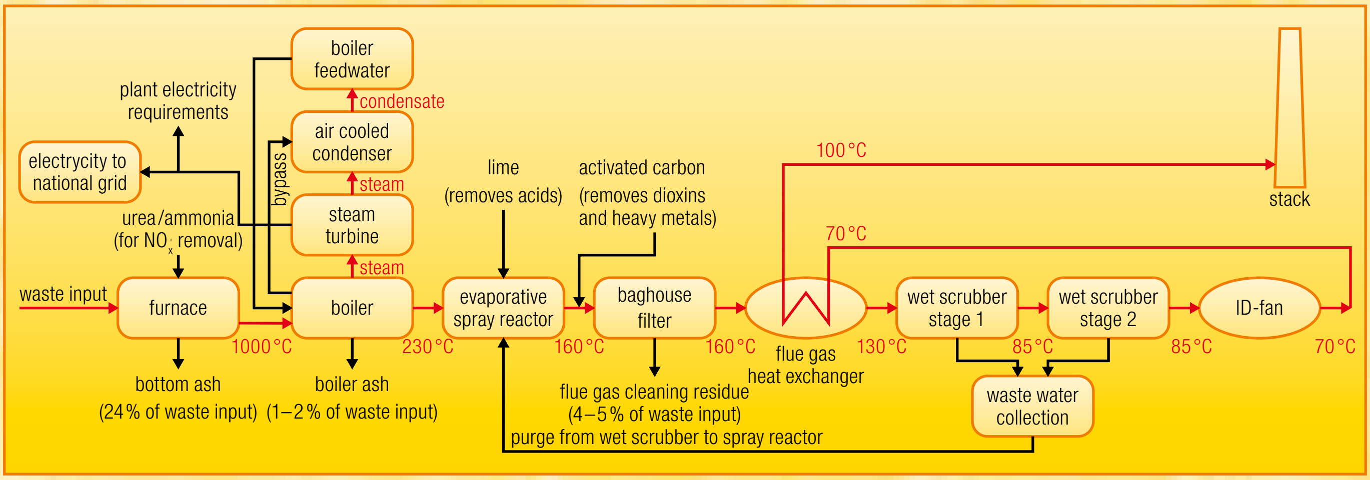


Figure 2: Process diagram of the proposed waste thermal treatment plant

Courtesy of Indaver Ireland

Treatment Process

Figure 2 outlines the WTT process diagram. MSW was assumed to consist of 70 % biogenic material, 17 % fossil material and 13 % inert material (EPA, 2004).

Only CO_2 emissions from the incineration of carbon of fossil origin (i.e. plastics, certain textiles, rubber, liquid solvents and waste oil) are reported (Penman et al, 2000).

N_2O emissions from combustion were estimated as 5×10^{-5} t / t MSW (Smith et al, 2001).

For both landfill scenarios, LandGEM (USEPA, 2005), a first order decomposition model was used to estimate CO_2 and CH_4 emissions over the life of the landfill (Figure 3).

Emissions were dependent on waste composition inputs, fraction of dissolved organic carbon dissimilated and CH_4 fraction (by volume) in the landfill gas.

Onsite landfill electricity demand was approximately 0.1 kWh / t MSW landfilled (Mendes et al, 2004). Under scenario L1 this demand was sourced from the national grid. Under scenario L2 it was met by onsite electricity generation.

Disposal / Use

The collection, transportation and disposal (or further treatment) of by-products from the incineration process were included in the analysis. Bottom ash was assumed to be transported off site to a nearby non-hazardous landfill, approximately 6 km away. All fly ash requiring hazardous waste disposal was assumed to be transported offshore to Antwerp due to the absence of such a facility in Ireland. The total distance by road is approximately 500 km and the quantity of ash generated required 455 trucks of 22 tonne capacity annually. Emissions arising from ferry travel were considered negligible. Ferrous metals collected for recycling from bottom ash amount to 4000 t / yr. Recycling steel avoids emissions of 1.49 t CO_2e / t of metal recovered compared to the production of virgin steel (Smith et al 2001). This includes all associated GHG emissions from transportation, treatment processes, and the disposal / use of any by-products.

Landfill sites operating to best practice collect leachate and treat it onsite. Based on leachate chemical oxygen demand (COD) assumptions, a 70 % leachate recovery rate and an energy demand of 215 kWh / t COD treated (Mendes et al, 2004), 30 kW was calculated, sourced from onsite energy generated under scenario L2.

Landfilling of MSW can lead to long term sequestration of the biogenic fraction of the MSW. The quantity of stored carbon was calculated using the degradable organic carbon fraction in the landfilled MSW and the fraction of DOC dissimilated.

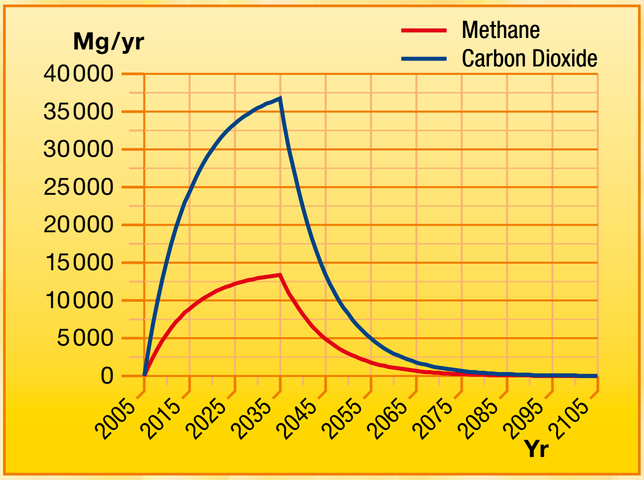


Figure 3: Annual CH_4 and CO_2 emissions from the landfill over 100 years

Displaced Emissions

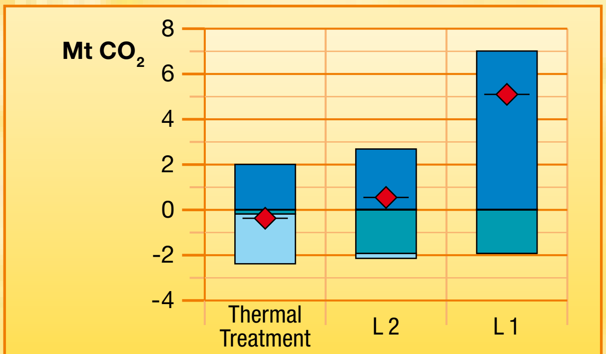
Displaced emissions from energy generated from the WTT process were calculated on the basis of the net heating value of the waste in 2000 (10.58 GJ / t MSW) multiplied by electricity (20 %) and heat (50 %) conversion efficiencies and the average national energy GHG emissions factor (0.76 kg CO_2 / kWh). The onsite operational energy demand of 3 MW was subtracted from the potential energy generation capacity with the rest being exported to the grid.

Displaced emissions arising from the utilisation of surplus heat were calculated based on replacing an oil fired boiler, with a heat conversion efficiency of 50 %. The emission factor of heating oil was assumed to be 0.075 t CO_2e / GJ.

Displaced emissions from energy generated from landfill gas under scenario L2 were calculated from assumptions of gas recovery of 70 %, collection and energy conversion efficiencies of 60 % and 30 % respectively. A heating value for landfill gas of 16 MJ / m^3 was applied to the methane production estimates from LandGEM to calculate a generation capacity of 5.73 MW of which 4.6 MW was available for export to the grid after meeting onsite energy demands.

Uncertainty and Sensitivity Analysis

Monte Carlo analysis was used to assess uncertainty and conduct a sensitivity analysis. Each parameter was assigned an uncertainty range (Table 2) and the simulation run with 10,000 iterations. The overall uncertainty associated with the total estimates of GHG impact of each scenario were calculated based these possible parameter ranges.



	Thermal Treatment	L2	L1
Net Emissions	-0.37	0.55	5.10
Process Emissions	1.99	2.66	6.99
Transport Emissions	0.02	0.03	0.03
Disposal Emissions	-0.18	-1.92	-1.92
Displaced Emissions	-2.20	-0.22	0.00

Figure 4: Total lifecycle greenhouse gas flux (Mt CO_2) of each waste treatment scenario. Thermal treatment balance does not take into consideration the utilisation of process heat.

Results

The results of the 30 year lifetime of each project indicate incineration of MSW provided the best GHG emission option (Figure 4). Process emissions dominated the GHG balance in all scenarios, however the displaced emissions provided by the generation of electricity from WTT more than offset this resulting in a net reduction in GHG emissions. The long term sequestration of biogenic C in landfill was found to be equivalent to 1.9 Mt CO_2 over the 30 year lifetime. In all cases transportation had no significant effect on the GHG balance.

Uncertainty in the estimates generated for the WTT scenarios were 11 % for both the heat and electricity options. A total uncertainty of 10 % was calculated for the L1 option. Associated uncertainty increased significantly to 42 % for the L2 scenario, caused by the gas extraction efficiency for use in energy conversion (Figure 5).

Whilst the range of uncertainty was large between the scenarios, the GHG lifecycle estimates remained significantly different.

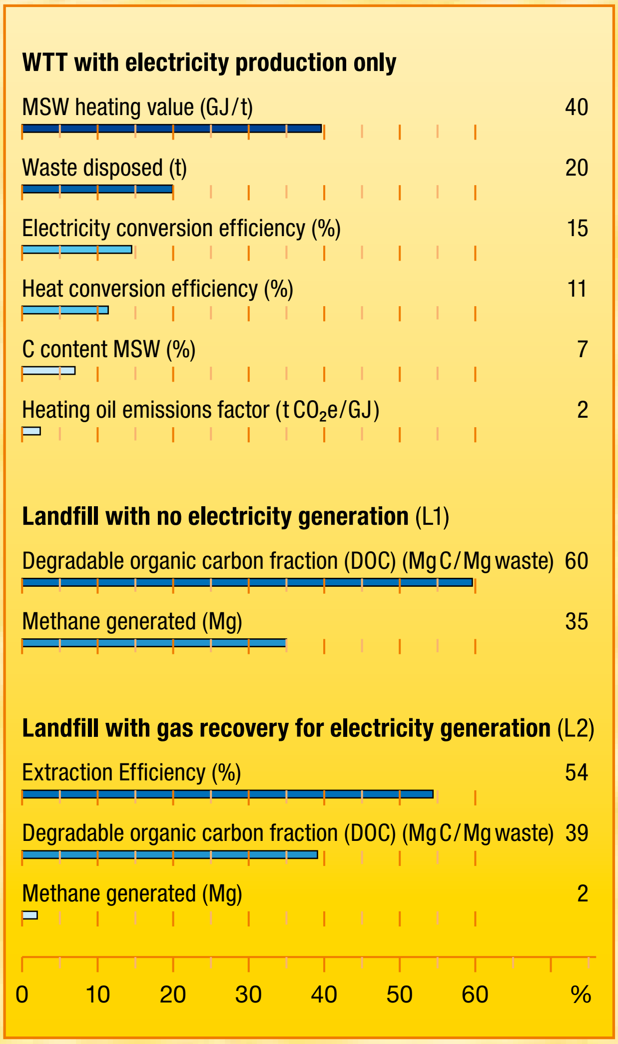


Figure 5: Contribution to variation in the mean estimates by model input parameters (95 percentile)

Discussion

Thermal treatment of MSW is new technology to Ireland and features strongly in the national long term management of MSW (Anon, 1998). The results of this work indicate that a shift from landfill to thermal treatment with energy recovery will reduce the net GHG flux associated with MSW disposal.

Increase in recycling, the preferred option in the waste management hierarchy, is likely to have an impact on the GHG balance of a WTT plant in the future by affecting the waste calorific value and the amount of ferrous material collected from the bottom ash for recycling. Should the national recycling targets for 2010 and 2020 (Anon, 1998) be met, the heating value of waste available for WTT could be reduced to 8.95 GJ / t MSW by 2020. Additionally, the amount of ferrous material collected from the bottom ash would fall from 4 000 t / yr to 600 t / yr. Recalculating GHG emissions based on these assumptions results in the WTT plant emitting 0.02 t CO_2 / t waste by 2020. Even though the WTT plant becomes a net contributor to atmospheric GHG under the 2020 waste composition assumptions, emissions still remain significantly lower than the best landfill scenario. Internal demand for recyclable material is low as no materials recycling plants operate within the country. All collected material for recycling is transported offshore resulting in increased economic and environmental costs. More importantly any benefits from recycling materials are accounted for in the processing country.

The GHG balance calculated for the landfill scenarios should also be discussed in the context of national GHG inventories. While avoided CO_2 emissions from sequestration of some of the carbon in the biogenic waste in the landfill should be calculated in this type of comparison, these avoided emissions would not be reflected in Ireland's national greenhouse inventory. If the results are considered in this context then the emissions from the landfill scenarios are significantly increased to 0.41 t CO_2e / t waste under L2 and 1.17 t CO_2e / t waste under L1.

Fossil carbon (i.e. plastic material and fossil fuel based textiles) can also be sequestered in landfill however its inclusion in any GHG lifecycle analysis would be double counting as carbon in such materials was already 'locked up' in fossil fuels so there is no change in its status.

Table 1

Summary of Results (t CO_2e / t waste). Negative values indicate a removal of GHG, positive an emission in GHG.

	Thermal Treatment	Landfill 1	Landfill 2
Transportation	0.004	0.005	0.005
Process emissions	0.33	1.17	0.44
Disposal / Use	-0.03	-0.32	-0.32
Displaced Emissions (Electricity Only)	-0.37	0	-0.04
Total	**-0.06**	**0.85**	**0.09**

Table 2
Parameters and applied uncertainty

Parameter	Value	Uncertainty / Range
Transportation		
Small Lorry (SL) (kg CO_2 / km)	0.45	10 %
Medium Lorry (ML) and Refuse collection vehicle (RCV) (kg CO_2 / km)	0.71	10 %
Large Lorry (LL) (kg CO_2 / km)	0.84	10 %
Total distance travelled (km)	various	2 %
National energy emission factor (kg CO_2 / kWh)	0.624	5 %
Process		
Quantity of waste (t)	200 000	180 000 – 200 000
C content of fossil component (%)	58	10 %
Fossil waste in MSW stream (%)	18	5 %
Incinerator burn out efficiency (%)	95	95 – 99
Methane generation capacity (t CH_4/t MSW)	105	8 %
Fraction of CH_4 in landfill gas (%)	50	40 – 60
Methane generation rate, k (yr^{-1})	10	7 – 12
Gas extraction efficiency (%)	70	60 – 90
% landfill gas flared	20	10 %
% landfill gas oxidised at surface	10	2 %
Disposal / Use		
Recycling of ferrous material (t)	4000	10 %
Ferrous recycling emission factor (t CO_2 / t)	-1.49	10 %
Degradable organic carbon fraction (DOC) (t C / t MSW)	0.194	5 %
Fraction of DOC dissimulated (DOCF)	0.55	0.5 – 0.6
Displaced Emissions		
Electricity generation efficiency (%)	20	18 – 22
Heat recovery efficiency (%)	50	44 – 55
Heating value of MSW (GJ / t)	10.58	10.00 – 12.50
GHG emission factor heating oil (kg / GJ)	74.9	5 %
Irish emission factor for grid generated electricity (kg / kWh)	0.624	5 %
Energy utilisation efficiency (%)	60	10 %
Energy conversion efficiency (%)	30	5 %
Heating value of landfill gas (MJ / m^3)	16	12 – 18

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Acknowledgements

This work was completed with contributions and advice from Hannes Schwaiger, Gerfried Jungmeier, Jackie Keaney, Judith Bates, Kenneth Byrne and Annette Cowie.

Financial support for this project was provided by IEA Bioenergy Task 38.

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Task 38

IEA Bioenergy (www.ieabioenergy.com) is an international collaborative agreement, set up in 1978 by the International Energy Agency (IEA) to improve international cooperation and information exchange between national bioenergy research, development and demonstration (RD & D) programs. IEA Bioenergy aims to realize the use of environmentally sound and cost-competitive bioenergy on a sustainable basis, thereby providing a substantial contribution to meeting future energy demands.

IEA Bioenergy Task 38 brings together the work of national programs in all participating countries on GHG Balances for a wide range of biomass systems, bioenergy technologies and terrestrial carbon sequestration. As one example of work, case studies have been conducted by applying the standard methodology developed by the Task 38. The case studies have assessed and compared GHG balances of different bioenergy and carbon sequestration projects in the participating countries, and the Irish case study is one example.

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oefpbf07005

IEA Bioenergy: T38: 2007: 01
This folder was designed and published on behalf of IEA Bioenergy Task 38
by JOANNEUM RESEARCH Forschungsgesellschaft mbH, Steyrergasse 17, 8010 Graz, Austria. December 2007.