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Waste to Energy: The Carbon Perspective

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Waste-to-Energy in a CO_2-perspective

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1.Introduction

Waste-to-Energy (W-t-E) plants are key treatment facilities for municipal solid waste in Europe. The technology provides efficient volume reduction, mass reduction and hygienization of the waste. However, the technology is highly disputed in some countries. Many arguments have been presented for and against the technology. Climate change is a key issue in modern waste management, and it is crucial to understand the role of W-t-E with respect to potential contributions to CO_2-emissions and savings. The main aspects of accounting for these CO_2-emissions and savings are presented in the following.

The CO_2 account includes loads as well as savings. The CO_2 load is caused mainly by use of auxiliary materials and energy at the plant and the direct emissions from the plant through the stack. The saving in CO_2 is related to the energy and materials recovered at the plant. In the following presentation, the quantification is made in kg CO_2-equivalent per ton (1000 kg) of wet waste treated, and as a reference it is assumed that conversion of organic matter into biogenic CO_2 is neutral in a global warming context as argued by Christensen et al. (2009).

2. Loads

Manufacturing of the materials for the building and the machinery of the W-t-E plant as well as the energy used for the construction process constitute a CO_2-emission to the environment since fossil fuel is typically used in the upstream processes (construction of building, furnace, equipment, etc.). Only few quantifications exist of the CO_2 loads of the capital goods for W-t-E plants; the CO_2 load is likely to be in the range of 7-14 kg CO_2/ton waste treated (Frischknect et al. 2007; Brogaard et al. 2013) paying attention to the capacity as well as the lifetime of the various construction elements.

Electricity is used at the W-t-E plant, in a particular for cranes, fans and air-pollution-control. Electricity may also be used for flue gas condensation. The main controlling factor is the actual configuration of the plant and the air emissions values aimed at. For example, obtaining low emissions values for SO_2 requires use of more electricity, while low emissions of NOx may require additional supply of gas. The use of electricity is typical 65- 185 kWh/ton of waste treated (e.g. Astrup et al., 2009). The contribution of this to the overall CO_2-emissions depends on how this electricity is produced in the energy system. This aspect will be discussed later when setting up the CO_2-acount. If the W-t-E plant produces electricity to the grid, then the use of electricity at the plant must be accounted in the same way or a net value must be introduced only accounting for the net exchange with the grid.

The direct emission of fossil CO_2 is caused by the combustion of plastic and textiles of fossil origin. This means that the actual emission depends on the waste incinerated. In recent years measurements of the fossil CO_2 content of the flue gas as well as the application of indirect balancing methods suggest that the fossil CO_2-emission is in the range of 250-600 kg CO_2/ton of waste (Fellner et al, 2007; Larsen et al. 2013, Fuglsang et al.2014). The variation may be large between plants depending on the waste they treat.

3. Savings

The savings in CO_2-emissions appear as the energy and material recovered at the W-t-E plant off-set the production of energy and material from fossil-fuel based technologies, which would else have had to be produced outside the waste system. Thus, the quantity of energy and material recovered and which productions are avoided affect the overall CO_2-savings to be attributed to the W-t-E plant.

3.1 Energy recovery

The energy recovered can be in the form of electricity supplied to the public grid, steam typically delivered to a nearby industry, and heat supplied to a district heating system. The energy recovery depends on the technology of the incinerator as well as the calorific content of the waste (lower heating value reflecting the energy content minus the amount of water that has to be evaporated).

The electricity recovery can range from 0 to 30% of the lower heating value or from 0 to 875 kWh per ton of waste incinerated. Statistical data for 314 European W-t-E plants showed an average of 22% for electricity production only and 15% for electricity production when also heat is being recovered (Reimann 2012). Factors like construction costs, electricity prices and the local market for steam and heat affect how much electricity recovery a W-t-E plant will be designed for. The highest value reported is for the Amsterdam W-t-E plant which produces up to 31% electricity out of the lower heating value of the waste received.

The heat recovery is closely linked to local heat markets (Fruergaard et al, 2010). The highest heat recoveries are reported for plants located close to large district heating systems. Values typically range 5-85 % of the lower heating value without flues gas condensation and may reach higher than 90 % with flue gas condensation involving heat pumps. The flue gas condensation is associated with a significant use of electricity, and electricity and heat recovery must be addressed in combination. Data for Europe shows that the average heat recovery is 37 % when electricity is produced and 77% when only heat is recovered (Reimann, 2012).

3.2 Material recovery

The material recovery is primarily from the bottom ash where metal scrap as well as a gravel-like material can be recovered. In terms of CO_2-savings the former is the most important contribution. Recovery of hydrochloric acid and excess lime from the air-pollution-control residues is rare and is not addressed here.

The scrap metal recovery is primarily in terms of magnetic iron and steel that can be removed by a magnet. Aluminum and in some cases also copper and brass can be removed by eddy-current technology. The metals are often present as very small particles and their recovery requires various pretreatment steps with size fractionation and homogenization in order to obtain high recovery. The actual scrap metal recovery depends on the waste composition as well as the technology available but in state-of-the-art cases the recovery can be expected to reach 85 % of magnetic iron and around 60 % of non-ferrous metals in the waste (Allegrini et al., 2014). Typically this would correspond to 15-30 kg of magnetic iron and 1.2-2.5 kg of aluminum per ton of waste treated. Recycling of metals saves about 1.5 kg CO_2 per kg iron scrap and about 10 kg CO_2 per kg aluminum (Damgaard et al., 2009). The recovery of metals at W-t-E plants is on the increase; in Europe the average recovery is estimated to 60%

In some countries, after initial metal sorting and storing, bottom ash can be used in civic works typically as unbound layers in roads as a substitute for gravel. The environmental burden with respect to climate impacts of gravel production or crushing of rock is relative small; typically 1.5-2 kg CO_2 per ton of gravel excluding the transport (Birgisdottir et al., 2006). Assuming that 1 ton of bottom ash can substitute in average for 0.8 ton of gravel, a typical saving by recovering bottom ash for civic works is of the order of 0.5 kg CO_2 per ton of municipal waste treated.

4. The CO_2 account for W-t-E

In quantifying the climate contribution from W-t-E we applied the commonly accepted approach of using three independent quantifications: “Indirect, upstream” (CO_2-loads from production of facilities, use of materials and energy), “Direct” from the plant (CO_2-loads from combustion of fuels and fossil carbon in the waste) , and “Indirect, downstream” (CO_2-savings taking place outside the waste management system obtained by energy delivered to the grid and materials sent to recycling or utilization) (see e.g. Gentil et al., 2009a) This approach was implemented by Astrup et al. (2009) on incineration of municipal solid waste as well as solid recovered fuels; some of the basic data used there have also been used in Table 1 where the climate contributions are quantified. Astrup et al. (2009) showed that contributions from use of lime, carbon filters etc. were small and they are excluded from Table 1 in order to focus on the main aspects. We present rounded numbers assuming a Lower Heating Value of 10 GJ/ton waste (1000 kg).

The electricity consumption as well as the recovery are important factors in the accounting and we have chosen to use different sources for producing electricity ranging from the EU mix (0.5 kg CO_2/kWh) to brown coal (1.3 kg CO_2/kWh).

The heat recovery is assumed to substitute for heat otherwise produced by fossil fuels. The heat substitution is highly affected by local conditions; however in most European cases natural gas is a likely alternative corresponding to around 75 kg CO_2/MJ heat.

Table 2 shows the CO_2 account for 8 different hypothetical W-t-E plants incinerating the same waste but with different energy recoveries and interactions with different energy systems with respect to electricity and heat. If no recovery took place, the net CO_2 emissions would be more than 400 kg CO_2 per ton waste. Even with a moderate recovery of electricity (13%) the W-t-E plant will constitute a load to the environment in terms of CO_2-equivalents. The more energy recovered and the more “dirty” the energy to be substituted by the recovered energy, the more will the W-t-E plant contribute to reduce the emissions of CO_2-equivalents. If electricity and heat is recovered at a W-t-E plant in an area where the energy otherwise would have been produced from brown coal, the net saving would exceed 1000 kg CO_2-equivalents per ton waste.

4. Conclusion

Many aspects may contribute to the sustainability of Waste-to-Energy (W-t-E) plants; however, the CO_2-accounts presented here clearly illustrate that the energy recovery efficiency of the plants is a very important factor. Not only is the quantity of the recovered energy important, but the type of energy off-set within the public energy networks is also critical. The more fossil fuels that are substituted in the energy sector by the electricity and heat production from the W-t-E plants, the larger the CO_2-savings offered to society. The CO_2-accounting shows that W-t-E plants with little energy recovery may constitute an overall load to the environment with respect to CO_2-emissions, but with efficient electricity and heat recovery then these plants contribute significantly to reducing the climate impacts of modern waste management and appear much more climate friendly than when the waste is disposed of in landfills (Gentil et al., 2009b).

References

Allegrini, E., Maresca, A., Olsson, M. E., Holtze, M. S., Boldrin, A., & Astrup, T. F. (2014):: Quantification of the resource recovery potential of municipal solid waste incineration bottom ashes. *Waste Management*, **34**, 1627-1636

Astrup, T., Møller, J. & Fruergaard, T (2009): Incineration and co-combustion of waste: Accounting of greenhouse gases and global warming contribution. *Waste Management & Research,* **27***, 789-799*

Birgisdóttir, H., Pihl, K.A., Bhander, G.S., Hauschild, M.Z. & Christensen, T.H. (2006): Environmental assessment of roads constructed with and without bottom ash from municipal solid waste incineration. *Transportation Research, Part D, Environment and Transportation*, **11**, 358-368.

Brogaard, L., Riber, C. & Christensen, T.H. (2013): Quantifying capital goods (buildings, machinery, etc.) for waste incineration. *Waste Management,* **33**, 1390-1396.

Christensen, T.H., Gentil, E., Boldrin, A., Larsen, A.W., Weidema, B.P. & Hauschild, M.Z. (2009): C balance, carbon dioxide emissions and global warming potentials in LCA-modeling of waste management systems. *Waste Management & Research*, **27**, 707-715.

Damgaard, A., Larsen, A.W. & Christensen, T.H. (2009): Recycling of metals: accounting of greenhouse gases and global warming contributions. *Waste Management & Research*, **27**, 773-780.

Fuglsang, K., Pedersen, N. H., Larsen, A. W., & Astrup, T. F. (2014): Long-term sampling of CO2 from waste-to-energy plants: 14C determination methodology, data variation and uncertainty. *Waste Management and Research*, ***32***, 115-123

Gentil,E., Christensen,T.H. & Aoustin,E. (2009a): Greenhouse gas accounting and waste management. W*aste Management and Research*, **27**, 696-706.

Gentil,E., Clavreul,J. & Christensen,T.H. (2009b): Global warming factor of municipal solid waste management in Europe. *Waste Management and Research*, **27**, 850-860.

Fellner, J., Cencic, O. & Rechberger, H. (2007): A new method to determine the ratio of electricity production from fossil and biogenic sources in waste-to-energy plants. *Environmental Science & Technology*, **41**, 2579-2586.

Frischknecht, R., Althaus, H.-J., Bauer, C., Doka, G., Heck, T., Jungbluth, N., Kellenberger, D., & Nemecek, T. (2007): The environmental relevance of capital goods in life cycle assessments of products and services. *The International Journal of Life Cycle Assessment*, **12**, Special Issue 1, 7–17

Fruergaard, T., Christensen, T. H., & Astrup, T. (2010): Energy recovery from waste incineration: Assessing the importance of district heating networks. *Waste Management*, **30**, 1264-1272.

Larsen, A.W., Fuglsang, K., Pedersen, N.H., Fellner, J., Rechberger, H. & Astrup, T.F. (2013): Biogenic carbon in combustible waste: Waste composition, variability and measurement uncertainty. Waste Management and Research, **31**, 56-66.

Reimann, D. (2012). CEWEP Energy Report- III (status 2007-2010). Confederation of European Waste-to-Energy Plants-. Brussels.

Table 1: Greenhouse gas emissions account for a Waste-to-Energy plant (values are expressed per ton of wet waste (ww) incinerated, 1000 kg), partly based on Astrup et al. (2009)

Indirect: Upstream	**Direct: W-t-E plant**	**Indirect: Downstream**
CO_2-equivalents (kg/ton ww): • Building of plant: 7 - 14 • Electricity provision: 89-242 • NaOH provision: 0-25 • NH_3 provision: 0-11	**CO_2-equivalents (kg/ton ww):** ▪ CO_2-fossil from fuel oil combustion: 0.3-3.2 ▪ CO_2-fossil from natural gas combustion: 0-4.4 ▪ CO_2-fossil from waste combustion: 290 -550 ▪ CO_2-biogenic from waste combustion: 0 (GWP: 0) ▪ N_2O emissions: 1.5-29.8 (GWP=298)	**CO_2-equivalents (kg/ton ww)):** Energy substituted: ▪ Electricity: -171 to -933 ▪ Heat: -141 to -1188 Material recovery: • Magnetic iron: -22 to -45 • Aluminum: -15 to -25
Accounted (unit/ton ww): ▪ Building of plant: Brogaard et al. (2013) ▪ Electricity provision: 185 kWh ▪ NaOH provision: 0-7 kg ▪ NH_3 provision: 0-5 kg	**Accounted (unit/ton ww):** ▪ Combustion of fuel oil: 0.1-1.2 l ▪ Combustion of natural gas: 0-2 Nm^3 ▪ Combustion of fossil carbon in waste; typical: 80- 150 kg C ▪ Combustion of biogenic carbon in waste; typical: 165-195 kg C ▪ N_2O emissions: 5-100 g	**Accounted (unit/ton ww):** Energy produced of LHV: ▪ Electricity: 13-26 % ▪ District heat: 20-70 % Material recovery: • Magnetic iron:15-30 kg • Aluminum: 1.5 -2.5 kg
Accounted but minor: ▪ Fuel oil provision: 0.1-1.2 l ▪ Natural gas provision: 0-2 Nm^3 ▪ $CaCO_3$ provision: 0-8 kg ▪ $Ca(OH)_2$ provision: 0-1.3 kg ▪ Water provision: 0-1 m^3		**Accounted but minor:** ▪ Treatment and landfilling of APC residues: 0-50 kg ▪ Landfilling of bottom ashes: 230 kg
Not accounted: ▪ Transportation of waste to plant ▪ Pre-sorting of the waste ▪ Provision of heat for offices etc. ▪ Provision of activated carbon for dioxin removal	**Not accounted:** ▪ Emissions from stored waste ▪ Emissions of trace gases	**Not accounted:** ▪ Dispersedly emitted gases ▪ CO_2 uptake in solid residues ▪ Transport of residues to treatment and disposal facilities

Table 2: Greenhouse gas emissions account for 8 Waste-to-Energy plants with different energy recovery systems (values are expressed in CO_2-eqivalents per ton of wet waste (ww) incinerated, 1000kg)

	Case 1	**Case 2**	**Case 3**	**Case 4**	**Case 5**	**Case 6**	**Case 7**	**Case 8**
Electricity production	13%	13%	26%	13%	13%	26%	26%	13%
Electricity source	EUmix	EUmix	EUmix	EUmix	Hard coal	Brown coal	Hard coal	Brown coal
Heat production	0%	20%	20%	70%	70%	0%	20%	70%
Heat source	-	Natural gas	Natural gas	Natural gas	Natural gas	-	Natural gas	Brown coal
Indirect: Upstream:	**CO_2 equivalents per 1000 kg waste incinerated**							
Plant and machinery	10	10	10	10	10	10	10	10
Materials used	15	15	15	15	15	15	15	15
Electricity used	90	90	90	90	210	240	210	240
Direct:	**CO_2 equivalents per 1000 kg waste incinerated**							
Stack emission	300	300	300	300	300	300	300	300
Indirect: Downstream:	**CO_2 equivalents per 1000 kg waste incinerated**							
Electricity recovered	-170	-170	-340	-170	-405	-930	-810	-465
Heat recovered	0	-140	-140	-490	-490	0	-140	-1190
Materials recovered	-60	-60	-60	-60	-60	-60	-60	-60
Total	+185	+45	-125	-305	-420	-425	-475	-1150