The environmental and financial benefits of recovering plastics From residual municipal waste before energy recovery

THE ENVIRONMENTAL AND FINANCIAL BENEFITS OF RECOVERING PLASTICS FROM RESIDUAL MUNICIPAL WASTE BEFORE ENERGY RECOVERY

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ABSTRACT: A life cycle assessment was carried out to investigate the environmental benefits of removing dense plastics from household waste before burning the waste in an energy from waste (EfW) facility. Such a process was found to improve the climate change and non-renewable resource depletion impacts of the waste management system. A preliminary financial assessment suggests that the value of the plastics recovered in this way would be less than the reduction in electricity income for the EfW. However, if the plastics were separated by the householders and collected in a kerbside recycling scheme, the greater price commanded by the higher-quality reclaimed plastics means that the operation would financially viable Further work is required to assess the effectiveness of using both kerbside collections and mechanical recovery to reduce the plastics content and carbon intensity of EfW feeds.

KEYWORDS: energy from waste, life cycle assessment, plastic recovery, carbon intensity

1. INTRODUCTION

The relative environmental advantages of managing non-recyclable municipal waste in energy from waste (EfW), landfill or mechanical biological treatment processes have been debated for many years. Life cycle assessment (LCA) is one of the techniques used to inform the discussion. LCA is an environmental management tool that allows the determination of the environmental impacts and benefits of providing and using goods and services. LCA studies are based on the compilation of inventories of the materials and resources consumed and environmental emissions released during an activity. The results of the inventories are then aggregated using equivalence factors into standard categories such as climate change, acidification and human toxicity. Several computer-based tools are available to perform LCA studies and there is an international standard for carrying out and reporting LCAs (BS EN ISO 14040, 2006).

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A number of LCA tools have been developed aimed specifically at waste management processes; the principal ones being EASETECH, WRATE, Gabi and the USEPA DST. There is an extensive literature on the subject of waste management LCAs (for example Bates, 2009, Christensen et al, 2009, Finnveden et al, 2009, Michaud et al, 2010), and the predominant views are that materials recycling is generally environmentally beneficial and that a well-operated EfW has distinct environmental advantages over landfill. The benefit of EfW over landfill from the climate change perspective is particularly strong when the EfW is displacing power and/or heat produced from a carbon-intensive source such as coal. In recent years, increases in the thermal efficiency of EfW and improved aluminium and steel recovery rates from the EfW bottom ash have increased the environmental advantages of EfW compared with landfill. However, international commitments to reduce carbon emissions are reducing the carbon intensity of electricity generated – this in turn is reducing the environmental advantages of EfW (Burnley et al, 2015).

LCAs of waste management systems do not provide definitive results, not least because the results are very dependent on some of the assumptions made. The main areas of sensitivity being; the fossil fuel displaced by any energy from waste processes, the efficiency of the EfW, the scope for combined heat and power operation and whether credit should be given for the long-term sequestration of biological carbon in landfills.

The advantages and disadvantages of burning waste plastics in an EfW are less well-documented. In favour of this practice, contaminated and mixed plastics can only be recycled in very low-grade applications and the landfilling of plastic is not sustainable when inter-generational equity and the use of finite resources (oil) are considered. The arguments against burning plastics in an EfW note that plastics contain high levels of fossil carbon so cannot be classed as a “renewable fuel”. In addition, burning chlorinated plastics leads to increased scrubbing reagent use to reduce acidification impacts with a corresponding increase in solid waste.

This research adopts an LCA approach to investigate the impact of reducing the fossil carbon content of EfW feedstock by removing some plastics from the waste. However, there is a trade-off; the financial viability of EfW depends partly on the income from power sales and plastics are an energy rich fuel, whose removal would significantly reduce the saleable energy. A preliminary estimate is made as to whether the reduction in energy income could be offset by income from the sales of reclaimed plastics.

2. MATERIALS AND METHODS

2.1 Description of scenarios

This assessment is based on the management of 100 000 tonnes of municipal waste through a system of kerbside collection of dry recyclable materials (glass, paper and metals), kerbside collection of kitchen and garden waste for composting and combustion of the residual waste in an electricity-only EfW with an overall efficiency of 25%. The electricity produced is assumed to displace power generated from natural gas using a combined cycle gas turbine (CCGT). A small quantity of hazardous and electrical/electronic material is taken directly to landfill. In the baseline scenario, all the residual waste is treated by combustion in the EfW. In the plastics recovery scenario, 70% of the dense plastics are first removed from the residual waste by near infra-red (NIR) separation and sent for recycling into low-grade applications with the remainder going to the EfW.

The composition of the municipal waste (Table 1) is taken from Defra (2009) and based on a comprehensive review of previous waste compositional surveys. Although the data are over eight years old, they represent the most up-to-date values for the UK. Furthermore, the values are not significantly different than those used in the EASETECH LCA tool for western central Europe based on literature published over the period 2005-2009 (Møller et al., 2012).

In both scenarios the quantities of material extracted for recycling or composting are based on good UK practice using kerbside collection schemes, giving a dry materials recycling rate of 29% and a composting rate of 24%. This total of 53% was achieved by 50 English local authorities in 2014/15 (letsrecycle.com, 2016a). The compositions of the EFW feed is given in Table 1 and of the extracted recyclable material in Table 2.

Table 1. Composition of the household waste and EfW feed (%)

	Overall waste composition	EfW feed composition	
		Baseline	Plastics recovery
Paper and card	24	10	15
Plastic film	3.8	8.1	9.0
Dense plastics	6.2	13	4.4
Textiles	2.8	5.9	6.6
Absorbent hygiene products	2.3	4.9	5.5
Wood	3.6	7.6	8.5
Combustibles	6.1	12.9	14
Non-combustibles	2.7	5.6	6.3
Glass	7.9	3.3	3.7
Kitchen and garden waste	32	16.7	19
Ferrous metal	3.1	1.3	1.9
Non-ferrous metal	1.3	0.6	0.8
Material <10 mm	2.0	4.2	4.7
Electrical/electronic equipment	2.2	0.5	0.5
Household hazardous waste	0.5	0.1	0.1
Total (tonnes)	100 000	46 800	40600

Table 2. Composition of the recycling feedstock (%)

	EfW baseline	EfW plastics recovery
Paper and card	36	34
Glass	12	11
Ferrous metal	10	2.5
Non-ferrous metal	4.7	1.9
Kitchen and garden waste	45	42
Dense plastics	0	7.6
Total (tonnes)	52 800	59 000

The EfW is typical of UK facilities, consisting of a mass burn grate furnace and a boiler raising steam for power generation with an overall thermal efficiency of 25% (based on lower heating values). Atmospheric pollution abatement is by selective non-catalytic reduction (SNCR) NO_x control and semi-dry lime scrubbing followed by bag filtration. Ferrous and non-ferrous metals are reclaimed from the bottom ash and the ash is used as an aggregate substitute. The gas cleaning residues are landfilled in a hazardous waste site.

2.2 Life cycle assessment

Conventional LCA tools evaluate the environmental burdens of a particular product from raw material extraction, through product manufacture, distribution and use, to product disposal. Waste management LCA tools are not concerned with products during their lives, assuming all waste starts with zero impacts but consider the entire waste stream from the moment waste is discarded through collection, processing and final disposal of any residues to landfill (Boldrin et al., 2011). These tools also take account of any environmental benefits derived from replacing virgin resources in the production of materials or composts with recycled materials and of the benefits from replacing conventionally-produced energy with the outputs of EfW processes.

In this study, the requirements of the ISO standard for LCA were followed (BS EN ISO 14040, 2006) as far as possible. The analysis was carried out using WRATE (Waste and Resources Assessment Tool for the Environment), an LCA tool developed by the Environment Agency for England and Wales (Burnley et al., 2012).

The functional unit (or basis) of the study was the management of 100 000 tonnes of residual municipal waste and the system covered the collection of the wastes from the households, transport to the EfW or recycling facility and the reprocessing or landfill disposal of the solid residues from the EfW.

The life cycle inventories were calculated using WRATE's databases which were compiled from a number of sources. The chemical composition of each component of the waste stream was taken from the UK's National Household Waste Analysis Programme (Environment Agency, 1994). The burdens of the EfW, materials recycling and landfill processes were obtained from published sources and from plant operators and subject to peer-review. Inventories for resources used (such as lime, ammonia and carbon consumption by the EfW) were taken from the ecoinvent LCA database (Frischknecht et al., 2005).

The environmental burdens were categorised and then characterised using the ecoinvent database (Frischknecht et al., 2005) to calculate the environmental impacts. The categories are a sub-set of the CML 2001 (Guinée, 2002) categories considered by the UK's Department for Environment Food and Rural Affairs (Defra) to be most relevant for LCAs related to municipal waste management.

- Global warming potential over 100 years expressed as CO_2 equivalent
- Acidification potential expressed as SO_2 equivalent
- Generic eutrophication potential expressed as PO_4 equivalent
- Freshwater aquatic ecotoxicity (FAETP infinite) expressed as 1,4-dichlorobenzene (1,4-DCB) equivalent
- Human health (HTP infinite) expressed as (1,4-DCB) equivalent
- Depletion of non-renewable resources expressed as antimony equivalent.

2.3 Financial assessment

Estimates were made of the value of plastics reclaimed from mixed waste and from source segregated wastes and these were compared with the reduction in EfW power income resulting from the diversion of this material. The data for this analysis were obtained from the literature and trade prices as discussed below.

3. RESULTS AND DISCUSSION

3.1 Overall environmental impact

The environmental impacts expressed using the six categories above are summarised in Table 3.

Table 3. LCA results

	Units	EfW baseline	EfW plastics recovery
Climate change	t CO_2-eq	-10 000	-21 000
Acidification	t SO_2-eq	-83	-100
Eutrophication	t PO_4-eq	1.9	2.0
Freshwater eco-toxicity	t 1,4-DCB-eq	-5 600	-5 300
Human toxicity	t 1,4-DCB-eq	-70 000	-69 000
Abiotic resource depletion	t Sb-eq	-260	-350

With the exception of eutrophication, the results are all negative which means that there is an overall reduction in the environmental impacts in these categories. These benefits arise because the materials and energy recovery processes displace the emissions associated with the production of these products from conventional sources. These findings are consistent with most other waste-related LCA studies. The positive eutrophication burdens are due to the NO_x emissions from the EfW which are greater than the emissions from producing an equivalent amount of power from a CCGT plant.

In four of these categories, there are no significant differences between the impacts of the two scenarios. However, the plastics recovery scenario has a definite advantage in terms of resource depletion. The savings in crude oil use from recycling the plastics more than offsets the savings in natural gas use resulting from recovery the energy in the plastics. The most important differences between the two scenarios relate to the climate change impacts and these are discussed below.

3.2 Climate change impacts

The climate change emissions results for each stage of the waste management system are shown in Table 4 for the two scenarios. This demonstrates that removing plastics from the EfW feed more than doubles the overall climate change benefits of the waste management system. 57% of this improvement results from the plastics recycling process and the remainder is due to the reduced fossil carbon content of the EfW feedstock enabling the production of lower carbon intensity power.

Table 4. Climate change emissions (t CO_2-eq)

	EfW baseline	EfW plastics recovery
Residual waste collection	244	244
Kerbside collection	393	393
Transport to EfW and recycling facilities	478	493
Kerbside recycling (dry)	-20 100	-20 100
Kerbside recycling (composting)	-976	-976
Reclaimed plastics recycling	0	-6 330
EfW	8 470	3 190
Others (landfill, operation of MRFs etc)	1 250	1 780
Total	-10 200	-21 300

The climate change benefits of removing plastics from the EfW feedstock arise from the differing thermal efficiencies of the conventional and EfW power plants. Burning one tonne of methane (carbon content 75% and lower heating value 50 MJ kg^{-1}) in a CCGT power plant with an efficiency of 45% releases 440 kg of CO_2 per MWh of useful power exported. In contrast, burning mixed plastics (carbon content 54% and lower heating value 25 MJ kg^{-1}) (Environment Agency, 1994) in an EfW with an efficiency of 25% releases 1736 kg of CO_2 per MWh of useful power exported. Clearly, burning waste plastics in an EfW is, in CO_2 emission terms, a practice that should be avoided where a more beneficial management option can be found.

The benefits from recycling mixed waste plastics stated above are probably an over-estimate. The WRATE model assumes that polyethylene (PE) and polyethylene terephthalate (PET) are recycled into clean pellets or flakes that can be substituted for virgin materials on a one-to-one basis in closed loop manufacturing. In reality, plastics reclaimed from mixed waste will contain some contamination and it is more realistic to assume that they will be recycled into lower grade products such as wood substitute, traffic cones or used as a partial aggregate substitute in concretes as suggested by Siddique et al (2008). Such applications will have much lower environmental benefits than closed loop recycling, but even if no benefits are realised, removing the plastics from the EfW feedstock would still produce an additional carbon emissions benefit of 4770 tonnes of CO_2 per 100 000 t of waste processed in comparison with the baseline scenario.

The sensitivity of the results to changes in the thermal efficiency of the EfW plant and the carbon intensity of the displaced electricity generation are presented in Figures 1 and 2. For both the baseline and plastics recovery scenarios, increasing the thermal efficiency has a major impact on the environmental benefits of the system. Figure 2 demonstrates that, with the decreasing carbon intensity of conventionally-produced energy expected in the future, the removal of plastics from the residual waste becomes more important in achieving net climate change benefits from EfW.

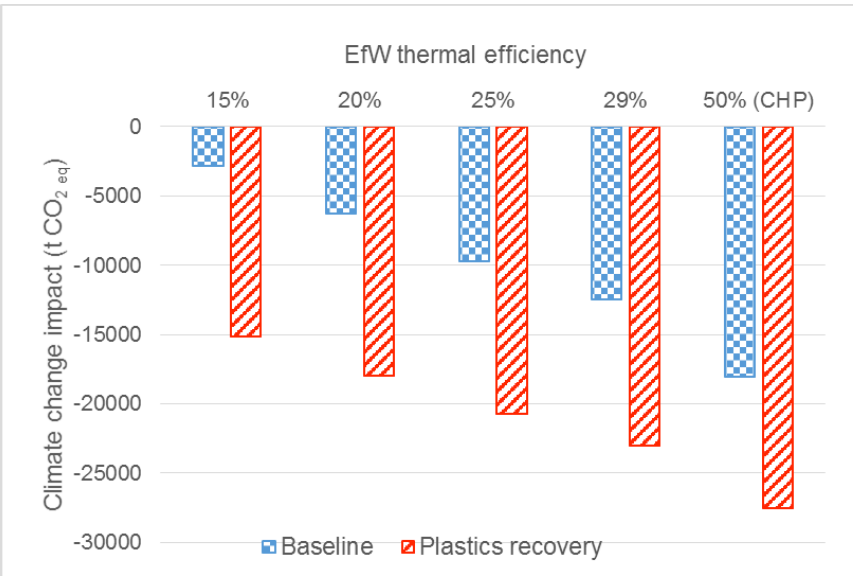

Figure 1. Sensitivity to EfW thermal efficiency

Figure 3 illustrates the variation in climate change impacts with changes in the efficiency of the plastics separation process. This shows that, once the insignificant impacts of operating the plastics recovery process have been taken into account, the process is beneficial with a linear relationship between plastics removal and carbon emissions reduction.

3.3 Financial implications

Plastics are separated from co-mingled recyclable materials in materials reclamation facilities (MRF) and some mechanical biological treatment processes involve plastics recovery as part of a much more complex series of processes.

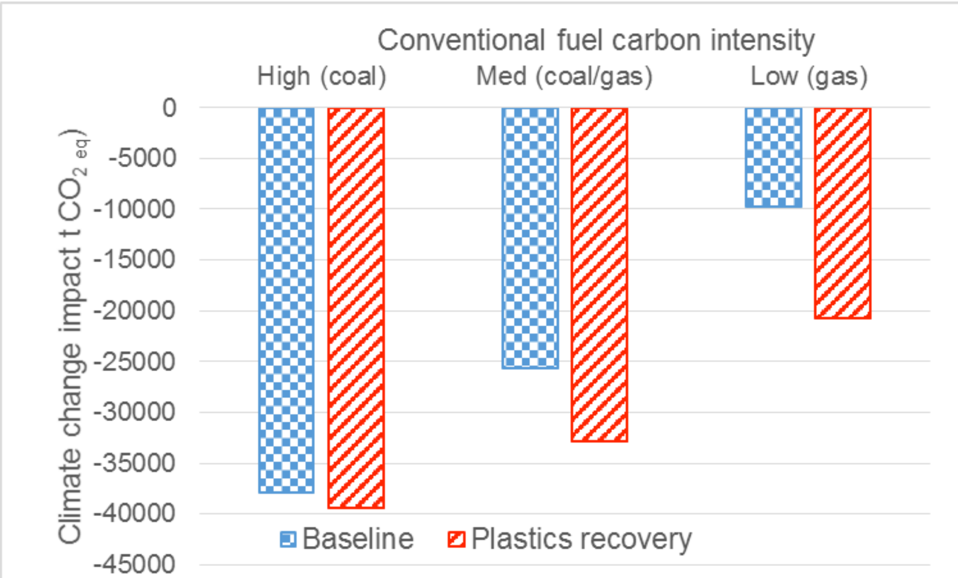

Figure 2. Sensitivity to power source displaced

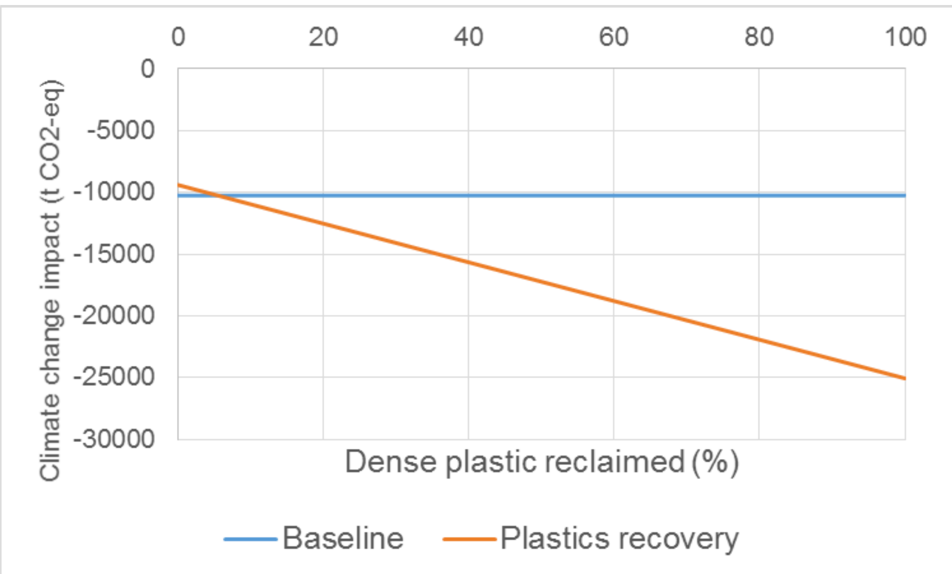

Figure 3. Sensitivity to plastics recovery efficiency

However, the recovery of plastics from mixed waste streams is not generally carried out, so the financial implications of plastic recovery can only be estimated. Financial data are usually commercially sensitive and only limited values are made public. Furthermore, published data tend not to relate to a specific process configuration.

Neidel and Jakobsen (2013) reported recovery costs in the range €86-200 per tonne for separating plastics from comingled recycling collections. In contrast Juniper's (2009) review of mechanical biological treatment plants reported plastic recovery costs in the range £30-65 per tonne (€36-79 per tonne – 29-06-2016).

The system considered in this research, a stand-alone plastics recovery process, generates income from the sale of the reclaimed plastics, but also leads to a reduction in electricity income at the EfW. Using the heating value and thermal efficiencies quoted above and an electricity price of £37 per MWh, the average APX spot price for June 2015 - May 2016 (APX, 2016), every tonne of plastics reclaimed represents a reduction in electricity income of £78. For the first six months of 2016, the market price of mixed plastic bottles ranged from £30-125 per tonne (Letsrecycle, 2016b) and it would be reasonable to assume that plastics collected from mixed waste would have a value towards the lower end of the range. When the cost of recovering the plastics is added to the loss in electricity income, it can be seen that the diversion of plastics from the EfW will not be cost-effective.

Further work, including pilot-scale tests of the effectiveness of processes to remove the plastics from EfW feeds and an assessment of the quality and value of the recovered plastic would be necessary to confirm these findings.

In reality a better option would be to incorporate the plastics recovery system into the kerbside recyclables collection scheme. This option would increase the quality of the reclaimed plastics and open up their use to higher-grade recycling. In this situation, WRAP (2009) modelled the cost of adding a NIR plastics recovery system to a MRF processing mixed recyclables from kerbside collection schemes. WRAP's key assumptions about capital and operating costs and the current energy and plastics prices are shown in Table 5.

Table 5. Cost of adding plastics recovery to the existing MRF

		Source
Capital cost	£580 000	WRAP (2009)
Operating cost	£115 600 /y	WRAP (2009)
Plastics throughput	1700 t/y	WRAP (2009)
Value of HDPE	£270-340 /t	Letsrecycle (2016b)
Value of PET	£80-150 /t	Letsrecycle (2016b)
Electricity price	£37 /MWh	APX (2016)

A discounted cash flow calculation was carried out, setting the rate of return to 5% and the project life to 10 years and taking the lower values for reclaimed plastic prices. This gives a project net present value (NPV) of £644 000 demonstrating that the project is financially viable. The sensitivity of the NPV to the value of the recovered plastic is illustrated in Figure 4 which indicates that the process would be financially attractive provided that the price received for the plastic does not fall below 26% of the mid-point of the ranges quoted.

These preliminary findings suggest that kerbside collection of dense plastics could be a cost-effective way of reducing the carbon intensity of EfW. Research is required to establish the quantity of plastic that could be collected in this way, the market value of the plastic and whether the scheme could also be used to collect plastic films. In addition, further effort should be devoted to finding recycling opportunities for the low-grade, mixed and contaminated plastics arising from an expanded kerbside collection scheme or from recovering plastics from mixed wastes.

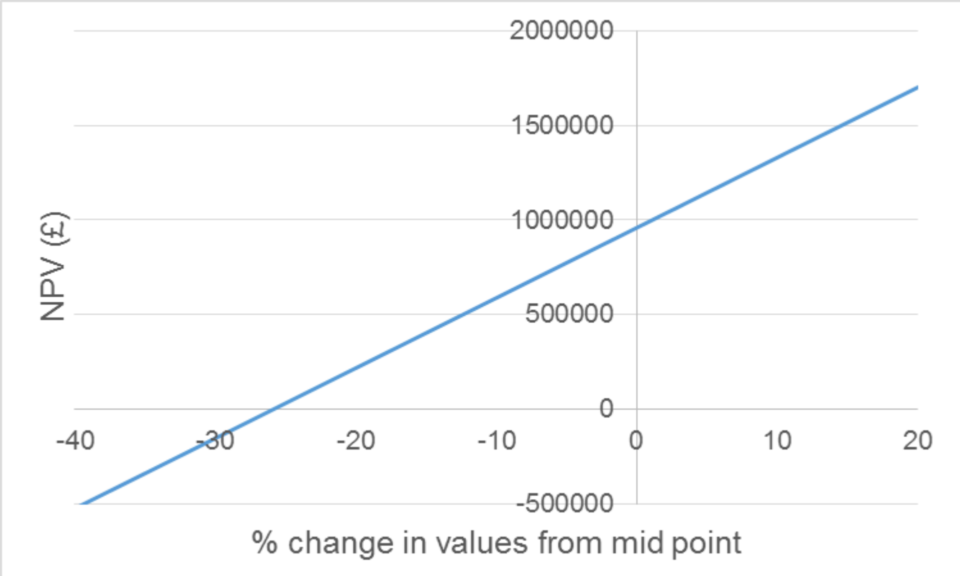

Figure 4. Sensitivity of NPV to recovered plastic value

4. CONCLUSIONS

Recovering and recycling dense plastics from household waste destined for combustion in an EfW facility provides distinct advantages when considering the non-renewable resource depletion and climate change impacts of the waste management system. Even if the recovered plastic is of a low grade and the recycling itself does not provide significant environmental benefits, the reduction in the fossil carbon content of the EfW feed means that the overall system with plastics recovery is still environmentally-beneficial.

Comparing the market values of the low-grade reclaimed plastics and of the electrical energy produced if the plastics were burned, indicates that the energy per tonne of plastic has the higher value. Therefore plastic recovery from the mixed waste is not economically-attractive.

If the dense plastics are collected through a conventional kerbside recycling scheme and processed to give a higher-grade product the situation is different. Using WRAP (2009) data for the additional capital and operating cost of installing plastics sorting equipment at the MRF suggests that the value of the high-grade plastics is greater than the additional costs of separation and reductions in electricity income.

All developed countries are seeking ways of reducing the carbon intensity of power generation and this offers a realistic way of reducing the carbon emissions associated with EfW. Further research is required to establish the extent to which kerbside collection can reduce the plastic content of the residual waste and whether such a scheme could be extended to cover film plastics.

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