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 impacts of the waste management system by 75% and the non-renewable resource depletion impacts by 18%. 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 leading to a loss of £2-5 million per year. However, if the plastics were separated by householders for a kerbside recycling scheme, the higher price commanded by the higher-quality reclaimed plastics and lower processing costs means that overall the operation would be financially viable giving a net present value of £768 000 at a 5% rate of return. In both cases, there is a further financial benefit to the EfW operator resulting from the additional gate fees for processing waste to replace the plastics removed. Further work is required to assess the costs and 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 residual 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 technique 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. Many 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).

Several LCA tools have been developed aimed specifically at waste management processes; the principal ones being EASETECH, Waste and Resources Assessment Tool for the Environment (WRATE), and the USEPA's Decision Support Tool (DST). There is an extensive literature on the subject of waste management LCAs (for example Villanueva and Wenzel 2007; Bates, 2009; Christensen et al., 2009; Finnveden et al., 2009; Michaud et al., 2010; Schott et al., 2016), 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 or gas. In recent years, improvements in 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 greenhouse gas emissions are reducing the carbon intensity of electricity generation – 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(s) displaced by any energy from waste processes, the efficiency of the EfW, the scope for combined heat and power operation, the global warming potential assigned to methane 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 in July 2017 China announced it was going to ban the import of certain lower grades of waste plastics collected for recycling. 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 requires more scrubbing reagent to reduce acidification impacts with a corresponding increase in solid waste.

This research adopts an LCA approach using WRATE 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 net efficiency of 25% (defined as the useful power exported to the electricity grid divided by the heat content of the feedstock). The electricity produced is assumed to displace power generated from natural gas using a combined cycle gas turbine (CCGT). A small quantity of electrical/electronic material is assumed to be reprocessed or recycled in an environmentally-neutral manner. In the baseline scenario (illustrated in Figure 1a), the recyclable and organic fractions are separated by householders for collection and all the residual waste is treated by combustion in the EfW. In the plastics recovery scenario (Figure 1b), this residual waste is first processed in a mechanical separation plant where 60% of the dense plastics are removed by near infra-red (NIR) separation and sent for recycling into low-grade applications with the remainder going to the EfW.

The EfW modelled with WRATE 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 the lower heating value or net calorific value). Atmospheric pollution abatement is by selective non-catalytic reduction (SNCR) for 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.

In both scenarios, the compostable and recyclable wastes are transported directly to the composting facility and materials recovery facility (MRF). Onward transport of compost and recyclate are not taken into account because these impacts would be the same in both cases and would also not be significant. In the baseline scenario, the residual waste passes through a transfer station en-route to the EfW which is assumed to be 30 km from the transfer station. In the plastics recovery scenario, the transfer station is replaced by the plastics separation process. The two scenarios are illustrated in Figure 1.

2.2 Performance of plastic separation processes

The automated separation of plastics from waste is mainly carried out in materials recovery facilities (MRFs) as part of the process of recovering plastics from mixed recyclable waste. The more technically-challenging process of segregating plastics from mixed waste is far less common. In both cases, published data on the performance and resource consumption of plastics separation operations are relatively sparse, but the following sources were identified.

WRATE includes a unit operation based on an MRF that is processing source-segregated recyclables in a semi-mechanised MRF using IR sorting for plastics separation. When developing the WRATE model, plant operators provided data for their process, including the energy consumption for the whole facility of 45 kWh per tonne. However, WRATE's peer-reviewers suggested that 10 – 20 kWh t^{-1} was typical of this type of plant and a value of 15 kWh per tonne was used in the WRATE models. This is comparable with the values reported in the following paragraphs. Discussions with experts indicated that the recovery rates for all materials were in the range 90-95% and a default value of 91.4% was selected for the WRATE model.

Foster (2008) reported trials using source-segregated mixed waste plastic packaging (excluding bottles) from UK household waste. The trials were undertaken at six commercial recycling or waste management companies using several sorting and cleaning technologies. NIR sorting mixed plastics at a rate of 3 tonnes per hour separated the different polymers generating products with a purity ranging from 87% (polystyrene) to 97% (polylactic acid). A combination of shredding, friction cleaning and wet separation was also trialled. Dry cleaning of the flaked material reduced dirt and paper contamination from 22% to 3%. Purities of 94% to 96% were achieved for PE, PET and PP. PE and PP were further separated using wet flotation and achieved up to 100% purity. However the product recovery was only 67%.

Evans and Kosior (2011) developed the work of Foster (2008) by investigating the cleaning and separation of plastic film from the reject streams of MRFs processing source segregated MSW and unsorted MSW. After shredding the plastics, which the authors commented were "heavily contaminated with dirt, grime and moisture", were cleaned in a dry process using spinning and abrasive actions process which reduced the contamination levels to 5% (MRF) and 10% mixed waste).

Combs (2012) developed a model of an MRF using data on plastics sorting equipment supplied by equipment manufacturers. The separation efficiency (defined as the percentage of the material in the feed recovered and sent for reprocessing) for PET was 98% and power consumption 15 kWh per tonne of PET and the corresponding figures for HDPE were 98% and 40 kWh t^{-1}. Montejo et al. (2013) developed Comb's work by incorporating data on the performance of eight MBT processes in Spain. Details of the plant configurations were not reported, but in all cases, plastics recovery was carried out manually. The most efficient plant in terms of plastic recovery reclaimed 36% of the HDPE, 24% of the PET and 60% of the LDPE. The average power consumption of the mechanical aspects of the eight plants (excluding composting/digestion related consumptions) was 15 kWh t^{-1}.

As part of an investigation of several systems for recovering plastic bottles for recycling, Rigamonti et al. (2014) considered a scheme where mixed waste was shredded, screened and subjected to NIR. The assumed recovery rate for plastic bottles was 100% and the process consumed 25 kWh per tonne of waste entering the MRF. In addition, 20% of the other plastics was recovered in a refuse derived fuel fraction containing 40% plastics. No details were given of the sources of any of the recovery or energy consumption values.

Hryb (2015) reported on trials from a test facility where unsorted waste was conveyed past a series of sensors (NIR, XRF, visible, X-ray) linked to air jets that diverted specific materials from the main stream. In two tests 93% and 45% of the plastics were recovered along with paper sheets. Contamination levels in the two tests were 47% and 56% respectively with residual waste/fines and composites accounting for the majority of the contamination. Higher power air jets were used in the first test, but no explanation was given for the differences in contamination rates. The process throughput was not reported, but the authors noted that the efficiency of the recovery process would depend on the amount of pre-treatment of the waste (bag breaking etc.) that the feedstock had been subjected to.

In a review of previous studies, Cimpan et al. (2015), reported on the separation efficiency of a number of MRFs and MBT plants. Plastics recovery figures of 39% and 45% for films, 45% and 67% for PET and 45 and 73% of HDPE were reported from two mechanised plants processing mixed MSW. In the case of the first plant, contamination levels were reported as 1.3% for PET and 1.7% for HDPE. Both plants used a combination of rotary screens, bag breakers, ballistic and air separators before using NIR sorting to recover the plastics. The authors also reported data from previous studies that achieved plastic recovery rates of up to 60%.

In a recent study by Feil et al. (2017), results from the Wijster MBT plant in the Netherlands which processes residual MSW using a system of coarse shredding, screening and NIR to recover RDF, SRF, metals and a plastic concentrate were reported. The plastic recovery rate at Wijster was 63% plastics and the corresponding figure from a second facility in the Netherlands was 60 ± 8%.

Clearly, there is some uncertainly over the performance of plastics separation equipment when processing mixed MSW and none of the literature comments on the long-term reliability and availability of such equipment. In the analysis below we have assumed that 60% of the dense plastics are recovered from the residual MSW before it is burned in the EfW. We have also assumed that the power consumption of the sorting equipment is 15 kWh per tonne of feedstock in addition to the power consumption of a typical transfer station.

2.3 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 do 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, 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 several 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 quoted in WRATE were obtained from published sources and from plant operators and were subject to peer-review during the development of WRATE. Inventories for the manufacture of the resources used (such as water treatment chemicals, lime, ammonia and activated carbon consumed 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.

2.4 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 changes in EfW power and gate fee income resulting from the replacement of this material with other feedstocks. Also, the cost of the alternative option of recovering plastics by kerbside collection and processing at a MRF was estimated. The data for these analyses were obtained from the literature and trade prices as discussed below.

3. RESULTS AND DISCUSSION

3.1 Waste and feedstock composition

The composition of the municipal waste (Table 1) is taken from Defra (2009) and based on a comprehensive review of then recent 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 from 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 43 of 319 English waste collection and unitary authorities in 2016/17 (Defra, 2017). The compositions of the EfW feed is given in Table 1 and of the extracted recyclable material in Table 2.

3.2 Overall environmental impact

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

With the exception of eutrophication, the results are all negative, meaning 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 (for example Parkes et al 2015). The positive eutrophication burdens in both the baseline and plastics recovery scenarios are due to the NO_x emissions from the EfW which are greater than the emissions displaced from producing an equivalent amount of power from the conventional electricity generation assumed to be displaced (CCGT).

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 resource depletion benefits are achieved because the savings in crude oil use resulting from recycling the plastics are greater than the savings in natural gas use that would be offset by recovering the energy in the plastics. The most important differences between the two scenarios relate to the climate change impacts and these are discussed below.

3.3 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 reducing plastics in the EfW feed increases the overall climate change benefits of the waste management system by 80%. 45% of this improvement results from the plastics recycling process (principally from the reduction in CO_2 emissions associated with manufacturing plastics from raw materials) with the remainder due to the reduced fossil carbon content of the EfW feedstock increasing the carbon advantage of the electricity produced by the EfW plant over the assumed marginal power plant (CCGT).

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 (note that the efficiency of 45% is used in the WRATE model although the latest CCGT plants operate at an efficiency of around 55%). This can be compared with burning mixed plastics reclaimed from waste. This material has a carbon content 54% and lower heating value of 25 MJ kg^{-1} (Environment Agency, 1994), which is significantly lower than that of non-waste plastics and is considered to be due to contamination by other low heating value wastes, such as food waste and liquids. Burning these plastics in an EfW with an efficiency of 25% releases 1160 kg of CO_2 per MWh of useful power exported. Koralewska (2008) reported efficiencies of up to 30%, but 25% represents the upper end of the range obtained from recent plants in the UK (Defra, 2014). For further comparison, coal is one of the most carbon intensive electricity fuels. While the CO_2 released depends on the carbon content and heating value of the coal and on the efficiency of the power plant, POST (2011) quote a range of 786-990 kg of CO_2 per MWh of electricity supplied. Clearly, burning waste plastics in an EfW is, in relation to CO_2 emissions, a practice that should be avoided where a more beneficial management option can be found regardless of the conventional fuel displaced.

The carbon intensity of burning plastic waste can be reduced by two means. Firstly, by reducing the contamination of the plastic feedstock by high-moisture components or, secondly, by increasing the efficiency of the power generation process. It is certainly possible to burn source-separated plastics which have a higher heating value and lower carbon intensity than mechanically-recovered plastics. However, given their value as a recycling feedstock and the drive to de-carbonise energy production systems, we do not consider this to be a practicable solution. Increasing the efficiency of the plastics-to-energy process would reduce the CO_2 emissions, but to achieve the levels from burning natural gas would require a plastic-to-energy process with an efficiency of 80% when compared to a 55% efficiency gas-fired plant.

The benefits from recycling mixed waste plastics stated in Table 4 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 in closed loop manufacturing (WRATE uses substitution rates derived from industry data. For HDPE this rate is 82.5%). 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. However, even if no benefits are realised from recycling, removing the plastics from the EfW feedstock (and allowing for the reduced amount of electricity generated) would still produce a carbon emissions benefit of 4650 tonnes of CO_2e per 100 000 t of waste processed in comparison with the baseline scenario.

3.4 Sensitivity analysis

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 2 and 3. For both the baseline and plastics recovery scenarios, increasing the EfW efficiency has a major impact on the environmental benefits of the system. Figure 3 demonstrates that, for a 25% efficient EfW plant, decreasing the carbon intensity of the conventionally-produced electricity displaced has an even greater effect on the climate change results and makes the removal of plastics from the residual waste more important in achieving net climate change benefits from EfW.

Figure 4 illustrates the variation in climate change impacts with changes in the efficiency of the plastics separation process for an EfW efficiency of 25% and displacing CCGT-derived power. This shows that, once the relatively low impacts of operating the plastics recovery process have been taken into account, the process is beneficial when the plastics recovery efficiency is greater than 6% with a linear relationship between plastics removal and carbon emissions reduction.

3.5 Financial implications

The separation of plastics from waste can potentially occur at the EfW as discussed in section 3.2 or at the household level along with other recyclable materials. In the former case, the costs and benefits of the process would normally accrue to the EfW operator and in the latter would likely to be shared between the waste collection company, the waste collection authority (WCA) and possibly the waste disposal authority (WDA).

3.5.1 EfW plastics recovery

Recovery of relatively pure plastic types from mixed municipal waste is now technically feasible as demonstrated in Section 3.2. 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 here. Financial data are usually commercially sensitive and only limited values are made public by operators. Furthermore, published data tend not to relate to a specific process configuration.

Juniper (2009) conducted an extensive review of the operation of MBT plants across Europe. This review was based on plant visits, discussions with operators and evaluation of designs for proposed plants. In a financial assessment, they reported plant operating costs in the range £30-65 per tonne of material input (€36-79 per tonne – 29-06-2016) which included capital and operating costs, but excluded income from product sales and disposal charges for reject streams. Many of the facilities considered included plastics separation processes, but it was not possible to separate the cost of plastics recovery from the total costs. In the absence of more reliable cost data, Juniper's values were used in this analysis. It should be noted that these costs are probably conservative as they include all the separation processes and the biological processing stages; many of these would not be necessary in a plant only designed to recover plastics.

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 potential reduction in electricity income at the EfW. Using the heating value and thermal efficiencies quoted above and an electricity price of £44.76 per MWh, the average APX spot price for January 2017 – December 2017 (APX, 2018), every tonne of plastics reclaimed represents a potential reduction in electricity income of £78.

For the first seven months of 2017, the market price of mixed plastic bottles ranged from an average £33 to an average £81 per tonne (Letsrecycle, 2018). Since the announcement by China in July that it would ban the import of most recycled plastics from 2018, the price has dropped to a range of £10 to £50/tonne. It would be reasonable to assume that plastics collected from mixed waste would have a value towards the lower end of the range and, although it is possible that plastics prices may recover partially, unless there is substantial investment in plastics recyclate reprocessing capacity, the loss of such a large market will inevitably affect prices in the longer-term.

In addition to the financial effects of plastics removal and recycling considered above, the prior separation of plastics has another potential financial benefit. EfW plant inputs are not normally limited by the weight of waste taken but by the heat released from its combustion. Therefore, removing some of the plastics from the waste will enable the plant to take in additional waste to generate the same amount of electricity. Assuming lower heating values of 10 MJ kg^{-1} for municipal waste and 25 MJ kg^{-1} for reclaimed plastics means that, for every tonne of plastic removed for recycling, the plant capacity is increased by 2.5 tonnes of municipal waste. If additional waste could be found (from commercial sources, for example), an EfW plant operator would not only be able to offset the reduction in electricity sales due to the 'loss' of plastics: if the additional waste input attracted the median gate fee for UK EfW plant in 2016 (WRAP, 2017) of £91 t^{-1}, the EFW operator will receive an additional income of £227.50 for each tonne of plastic recovered.

The additional income and costs associated with recovering plastics from a 100 000 tonnes per year EfW are summarised in Table 5. This suggests that recovering plastics from an EfW feedstock would not be economic unless the cost of separating the plastics from the waste is significantly lower than the estimated value and/or the price of recycled plastics is substantially higher than recent market trends. This analysis assumes that a stand-alone plastics recovery process is installed at the EfW. In reality, it is more likely that plastic removal would be carried out as part of an MBT process to recover other recyclable materials and produce an refuse derived fuel. The environmental and financial aspects of such a process is being investigated as part of the next phase of the research.

Further work, including a case study incorporating pilot-scale tests of the effectiveness of processes to remove the plastics from EfW feeds and an assessment of the costs, and the quality and value of the recovered plastics, would be necessary to validate these findings.

3.5.2 Kerbside recovery of plastics

In reality, a better option than separation from mixed waste may be to incorporate the plastics recovery system into the kerbside recyclables collection scheme (which already happens in a number of local authority areas). This option would increase the quality of the reclaimed plastics and open up their use to higher-grade recycling. The costs of an additional collection for dense plastics vary widely depending on several factors including: the nature of the existing and the proposed collection system, the existing and future vehicle utilisation and the demographics of the area and is beyond the scope of this paper.

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 with the authors’ energy and plastics prices are shown in Table 6.

A discounted cash flow calculation was carried out for different rates of return over a project life to 10 years and taking the mid-point values for reclaimed plastic prices. This gives project net present values (NPV) from ££40,400 at 30 % to £768,000 at 5% rate of return, demonstrating that the project is financially viable. The sensitivity of the NPV to the value of the recovered plastic is illustrated in Figure 5 which indicates that the process would be financially viable even if the price received for the plastic fell to 73% below the midpoint (or £26.60 per tonne for HDPE and £7.98 per tonne for PET).

These preliminary findings suggest that kerbside collection of dense plastics should 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.

4. CONCLUSIONS AND RECOMMENDATIONS

Recovering and recycling dense plastics from household waste destined for combustion in an EfW facility provides distinct advantages when considering the climate change impacts of the waste management system giving a 75% improvement . There are also benefits in terms of acidification (17% improvement) and the depletion of abiotic resources (18% improvement). There were no substantial differences regarding eutrophication, human toxicity and freshwater aquatic ecotoxicity. 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.

Reclaiming plastics from mixed municipal waste is not currently carried out on a commercial scale and there is no reliable information on the effectiveness or costs of such a process. The current market values of the low-grade reclaimed plastics is less than that of the electrical energy produced if the plastics were burned, which indicates that plastic recovery from the mixed waste is not economically attractive. For 100 000 tonnes a year of municipal waste and taking account of both the operating costs of a plastics recovery system (based on values given in the literature) and of the increase in capacity of the EfW resulting from plastic removal means that recovering and recycling plastics would result in a loss of £2-5 million per year.

An alternative would be for the WCA to collect dense plastics through a conventional kerbside recycling scheme and for these to be processed to give higher-grade products. Allowing for the additional capital and operating cost of installing plastics sorting equipment at the MRF and the savings in EfW gate fees, this process appears to be financially attractive for the WCA as long as reclaimed plastic prices do not fall below 27% of 2017 UK prices. Under current prices, such a scheme would yield a net present value of £768 000 at a rate of return of 5%.

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. Additional work, including a case study, is required to validate these findings. This further research should:

- demonstrate the technical feasibility of reclaiming dense plastics from mixed municipal waste;
- establish the cost of removing dense plastics from mixed wastes;
- determine the quality and market value of plastics recovered in such a way;
- 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; and
- determine the cost and effectiveness of using NIR technology to separate plastics from mixed recyclable material in a MRF.

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

	Overall waste composition	EfW feed composition	
		Baseline	Plastics recovery
Paper and card	24	10	11.1
Plastic film	3.8	8.1	8.7
Dense plastics	6.2	13	5.7
Textiles	2.8	5.9	6.4
Absorbent hygiene products	2.3	4.9	5.4
Wood	3.6	7.6	8.3
Combustibles	6.1	12.9	14
Non-combustibles	2.7	5.6	6.1
Glass	7.9	3.3	3.6
Kitchen and garden waste	32	16.7	18.1
Ferrous metal	3.1	1.3	1.4
Non-ferrous metal	1.3	0.6	0.6
Material <10 mm	2.0	4.2	4.5
Electrical/electronic equipment	2.2	4.7	5.1
Household hazardous waste	0.5	1.0	1.1
Total (tonnes)	100 000	46 640	42 920

Table 2 Composition of the recycling feedstock (t)

	EfW baseline	EfW plastics recovery
Paper and card	19 370	19 370
Glass	6 320	6 320
Ferrous metal	2 480	2 480
Non-ferrous metal	1 010	1 010
Kitchen and garden waste	24 180	24 180
Dense plastics	0	3 720
Total (tonnes)	53 360	57 080

Table 3 LCA results

	Units	Baseline	Plastics recovery
Climate change	t CO_2-eq	-11 200	-19 600
Acidification	t SO_2-eq	-89	-104
Eutrophication	t PO_4-eq	1.1	1.6
Freshwater eco-toxicity	t 1,4-DCB-eq	-5 600	-5 500
Human toxicity	t 1,4-DCB-eq	-68 000	-68 000
Abiotic resource depletion	t Sb-eq	-270	-320

Table 4 Climate change emissions (t CO_2-eq)

	EfW baseline	EfW plastics recovery
Waste collection containers	190	190
Recycling collections	400	400
Residual waste collection	350	370
Transport to EfW	300	280
Transfer station/plastic recovery plant	120	140
Dry materials and ash recycling	-23 200	-23 000
Compost use	-1 500	-1 500
Reclaimed plastics recycling	0	-3 800
EfW	10 800	6 200
Others (landfill, operation of MRFs etc)	1 340	1 120
Total	-11 200	-19 600

Table 5 Annual income and costs associated with plastics recovery from a 100 000 tpy EfW (£)

	Most advantageous	Least advantageous	Allowing for increased EfW input
Plastic separation costs	-3 000 000	-6 000 000	-3 000 000
Loss in electricity income	-503 750	-503 750	0
Income from plastic sales	186 000	37 200	186 000
Additional gate fee income			846 000
Total cost	-2 471 750	-5 471 750	-1 968 000

Table 6 Cost of adding plastics recovery by NIR separation to an existing MRF

		Source
Capital cost of NIR separator (installed)	£580 000	WRAP (2009)
Operating cost	£115 600 /y	WRAP (2009)
Plastics throughput	1700 t/y	WRAP (2009)
Value of HDPE	£90-110 /t	Letsrecycle (2018)
Value of PET	£25-35 /t	Letsrecycle (2018)
Electricity price	£45 /MWh	APX (2018)

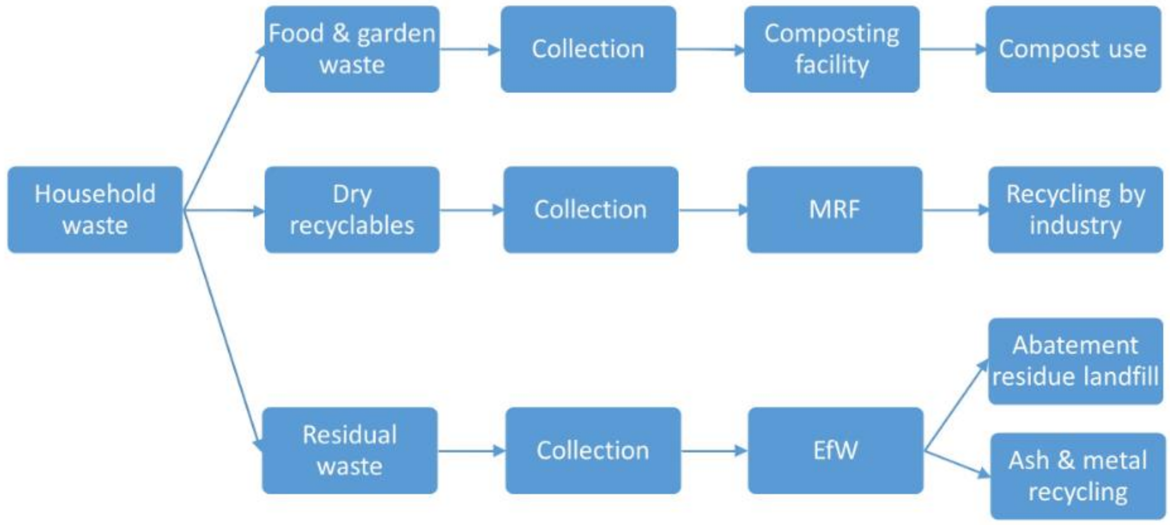

Figure 1a LCA baseline scenario

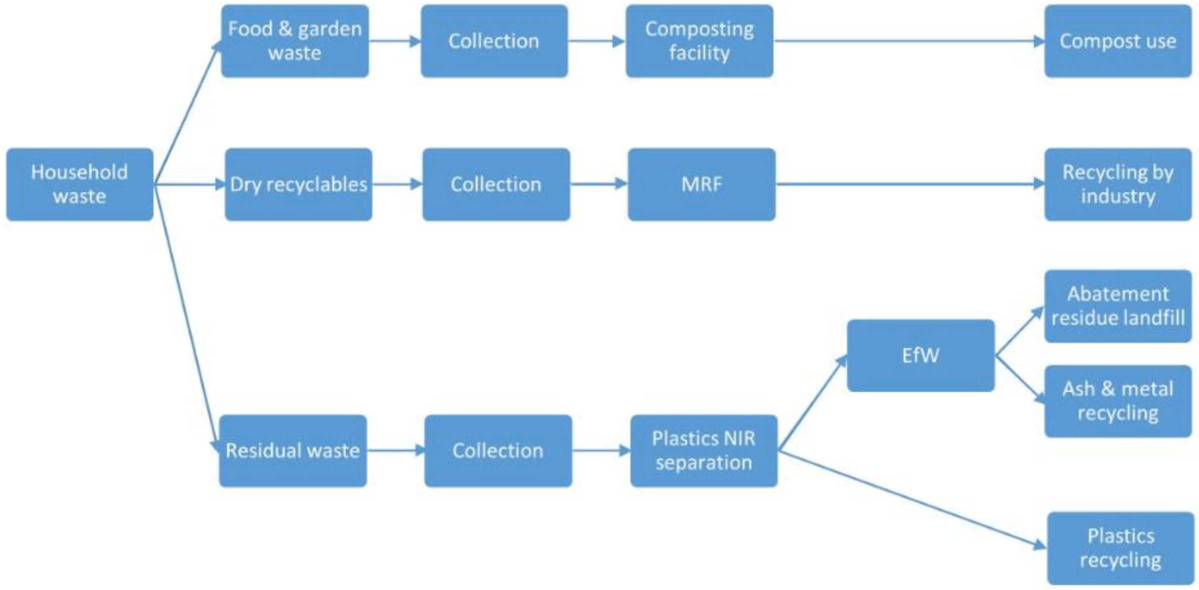

Figure 1b LCA scenario with mechanical recovery of plastics

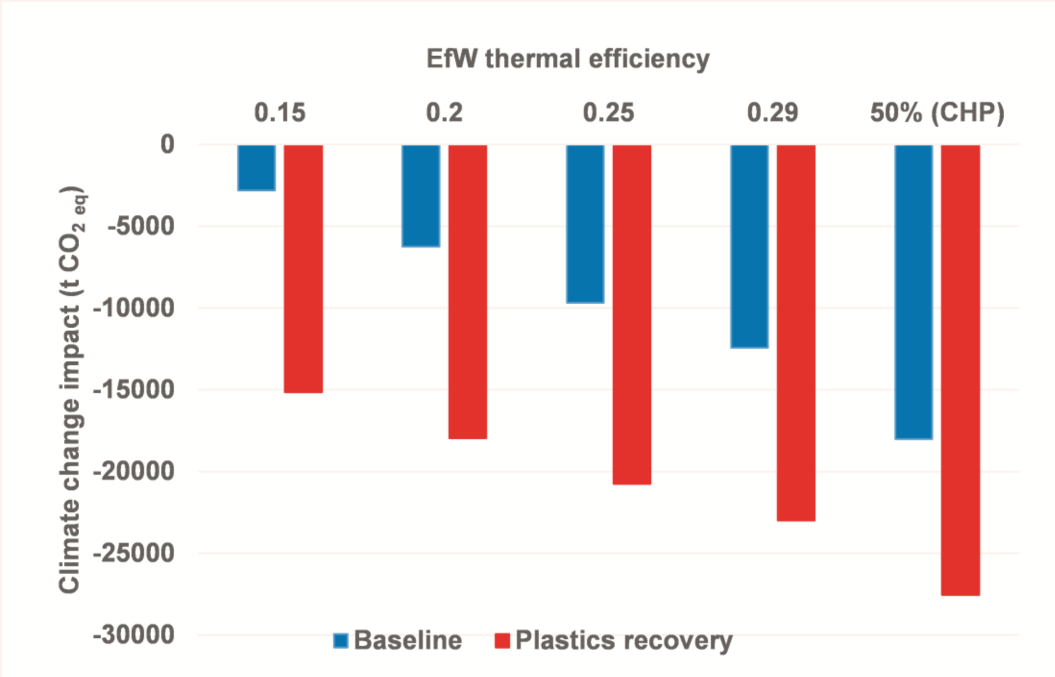

Figure 2 Sensitivity of climate change impacts to EfW thermal efficiency

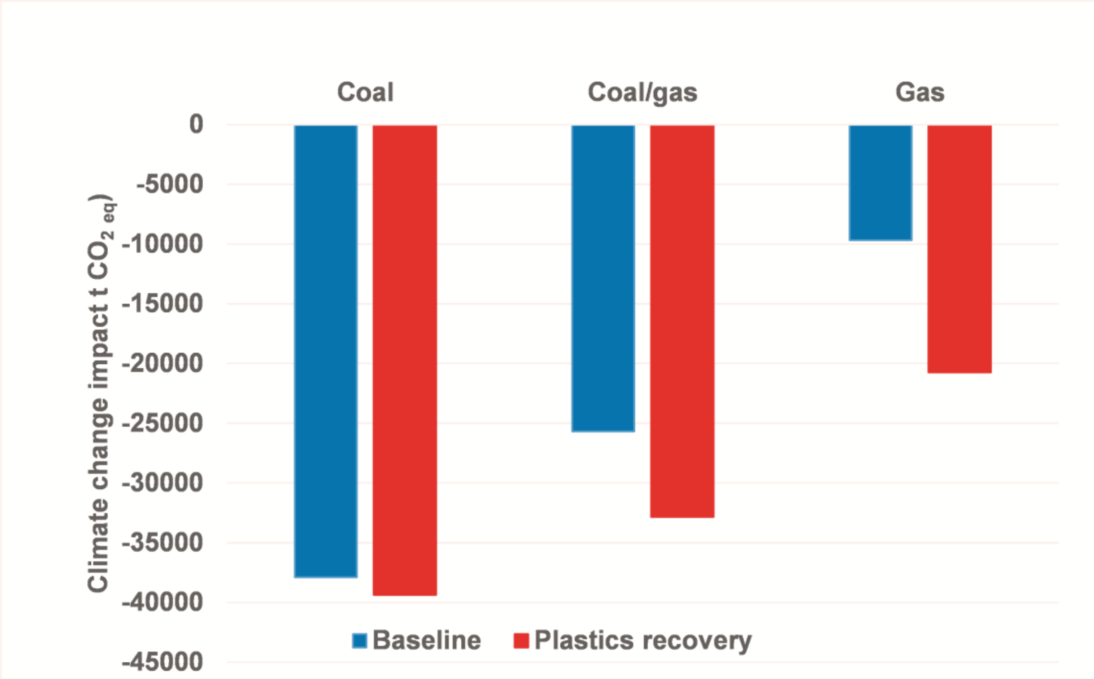

Figure 3 Sensitivity of climate change impacts to power source displaced

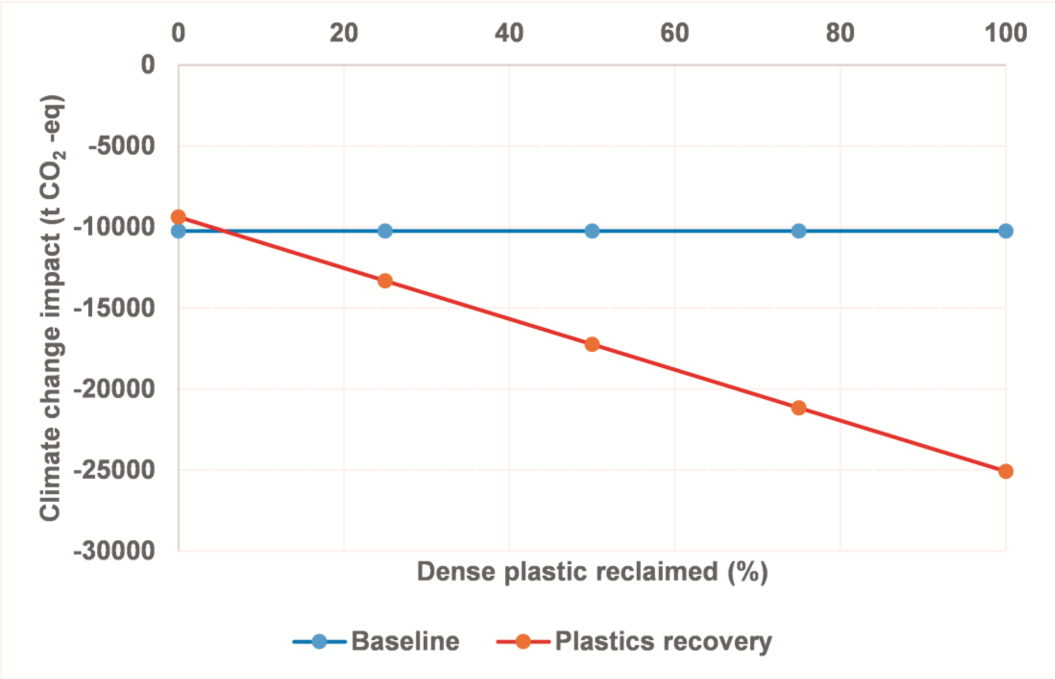

Figure 4 **Sensitivity of climate change impacts to plastics recovery efficiency**

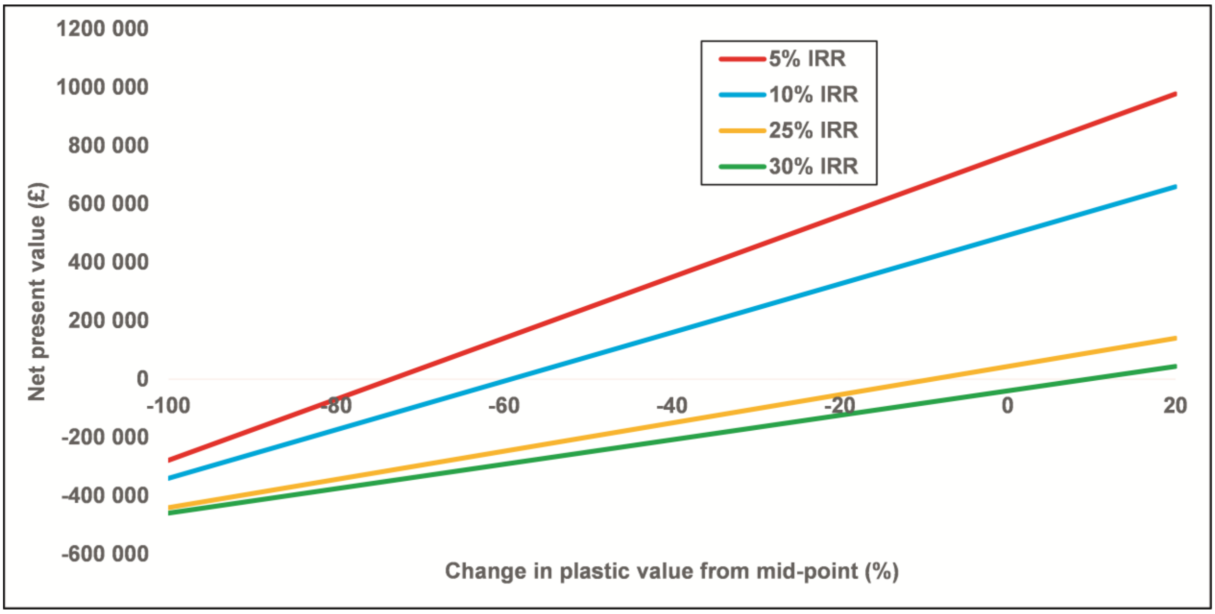

Figure 5 **Sensitivity of NPV to recovered plastic value**