

Improving Recycling Effort – Its Effect on the Calorific Value of Residuals

CONTACT

Matthew Chester, School of Civil Engineering, University of Leeds
Woodhouse Lane, Leeds. LS2 9JT.

Tel: +44(0)113 343 2241 Mail: m.j.chester@leeds.ac.uk

EXECUTIVE SUMMARY

The calorific value (CV) of waste is a function of its chemical composition which is altered as various waste fractions are recycled. However, not all households recycle effectively, and not all fractions of waste can be recycled. Different waste management strategies employed across the UK further alters the composition of the residual waste streams requiring disposal. Uncertainties in waste composition represent a risk to the business case and perhaps even inhibit investment in EfW plant. By approximating the waste stream as a hypothetical compound of the form $C_aH_bO_cN_dS_e$, its CV can be determined using a modified Dulong equation. Performing a parametric analysis using Monte Carlo techniques on various properties of the waste stream (e.g. carbon content, moisture content, etc.) and recycling participation rates and limits, enables the upper and lower bounds of the CV to be quantified.

The objective of this study was to examine how potential changes in the recycling behaviour of householders could affect the CV of residual waste. Four scenarios were developed and analysed to explore the effect that recycling has on the chemical content of residual waste streams and, therefore, on its calorific value: a business as usual (BAU) case using the current recycling rates of each category; a behaviour shift scenario explored the effect on recycling rate if each household ‘moved up’ a recycling category; a worst case scenario in which each household is a non-recycler; and a best case scenario in which each household becomes a super-committed recycler.

Plastics tend to dominate the variance of CV in all scenarios. They have one of the lowest recycling limits yet one of the highest relative CVs in the waste stream. Hence as plastic begins to dominate the residual stream it will have a greater influence on the CV. As recycling potential improves, results from this analysis indicate that the mean CV could increase from 10 to 15 MJ/kg because the relative proportion of plastics increases. However, there is a trade-off: as the CV increases the quantity of residuals decreases at a much greater rate such that a much larger ‘catchment area’ would be required to meet a facility’s operational capacity. Furthermore higher proportions of plastic in the residual stream means that more of the energy comes from a fossilised source so the ROC-able content of the waste will diminish.

Therefore new build EfW plant will need combustion technologies that can cope with a variation in CV should recycling rates improve in the future. Removal of recyclables reduces the mass of residuals considerably, which suggests that EfW plant might be better suited in locations close to large urban areas to ensure adequate throughput of feedstock. And since biowaste content is a dominant parameter, regions of the UK that employ a separate organics collection strategy may be more suitable for the location of EfW plant.

Regardless of the recycling potential of the public, householders can only generate waste from the products that they purchase. Therefore, rather than the existing ‘end of pipe’ approach to waste recovery, the onus should be on the manufacturer to change their ethos and supply products that can be managed sustainably.

INTRODUCTION

Waste Management routes are in a period of transition as the UK seeks to comply with mandatory targets of the Landfill Directive. Not only offering a potential solution to realising these targets, energy-from-waste (EfW) also provides a source of heat and power. Generation plant of the appropriate technology (e.g. pyrolysis or gasification) are eligible for Renewable Obligation Certificates (HMSO, 2009), thus bringing the UK closer to its renewable energy targets and simultaneously encouraging EfW. However, the use of EfW arouses a sense of suspicion with the public, whose concern is that recycling rates will be jeopardised as local authorities (LAs) seek to adhere to contractual waste tonnage obligations 'supplied' to the facility.

With the exception of anaerobic digestion, EfW technologies recover energy via thermal degradation¹ and the magnitude recovered is closely related to the calorific value (CV) of the waste, which is a function of its composition. Although the chemical composition of UK household waste is fairly constant on a dry basis (Chester *et al.*, 2008), kerbside collection of recyclables leaves a residual waste stream that requires treatment and disposal. The composition of this residual stream not only depends on social, economic, and demographic factors, but also on the level of public participation in recycling schemes. Uncertainty over residuals composition manifests itself as financial risk and perhaps even inhibits investing in EfW plant. Understanding how recycling effort influences the chemical composition of residuals, and hence the CV, will help to mitigate this risk.

RECYCLING HOUSEHOLD WASTE

Recycling can occur prior to waste collection or after it. Prior to collection waste is sorted at source, e.g. in the home into streams of recyclables determined by regional LA strategies. Where household recycling schemes do not exist or participation rates are low, waste can be sorted into recyclables post-collection via an automated process. In practice, however, it usually involves a combination of pre and post-collection recycling for two reasons. Firstly, that the kerbside collection of recyclables leaves a residual waste stream whose composition not only depends on social, economic, and demographic factors, but also on the level of public participation in recycling schemes. And secondly, the Household Waste Recycling Act 2003 mandates LAs to collect at least two recyclable streams and results in LAs collecting various types of recyclables (HMSO, 2003). For example, in West Sussex household residual waste is collected and delivered to an MBT facility that removes metals from the waste stream along with a fine biodegradable fraction. The metals are eventually reprocessed and the bio-fraction is treated via anaerobic digestion (Sinclair, 2006).

Availability of recyclable material is determined by the sorting efficiencies of the recycling system. For mechanical systems efficiencies used in the Environment Agency's LCA tool, WRATE, are estimated to be approximately 92% for most recoverable fractions, i.e. 92% of the material is recovered from the incoming waste. These efficiencies are dependent upon the choice of technology employed in the sorting plant. However, the recycling efficiency of the pre-collection system, i.e. the householder, is not so simple because of the reliance on the householder to participate in a scheme. The recycling potential of households has been assessed by WRAP (the Waste and Resources Action Plan) in order to "*generate a more rigorous, detailed and in-depth understanding of what prevents householders from recycling or recycling more than they could*" that will enable a more focused consumer campaign and ultimately improve the rate of recycling in the UK (Pocock *et al.*, 2008). UK householders were categorised into four groups: non-recyclers (6% of households), non-committed recyclers (23% of households), generally committed recyclers (41% of households), and super-committed recyclers (30% of households).

¹ Anaerobic digestion exploits methane generation from the biodegradable fractions of waste and uses it to generate energy. Pyrolysis and gasification use partial combustion to release syngas which is then combusted, and incineration use full combustion.

A physical barrier to recycling is also present as not all fractions of waste can be recycled (yet). In order to gauge the effectiveness of recycling strategy and inform future recycling policy, Friends of the Earth (FOE) have assessed the recycling potential of household waste (FOE, 2007). The recycling limits have been aggregated into the primary waste categories listed in Table 1.

Table 1: Aggregated Recycling Limits of Household Waste [Source: FOE (2007); Chester et al (2008)]

Category	Mean %wt	FOE Max	Recycling Rate 100%
Card	8.81%	73.00%	6.43%
Combustibles	6.80%	30.12%	2.05%
Dense Plastic	6.24%	44.65%	2.78%
Ferrous Metal	2.63%	78.00%	2.05%
Fines	2.65%	80.00%	2.12%
Garden waste	10.18%	90.00%	9.17%
Glass	6.76%	74.97%	5.07%
Hazardous Household	0.44%	5.93%	0.03%
Kitchen waste	25.98%	83.85%	21.78%
Miscellaneous	0.73%	0.01%	0.00%
Non-Combustibles	2.01%	57.56%	1.16%
Non-Ferrous Metal	1.20%	78.00%	0.94%
Paper	16.28%	60.27%	9.81%
Plastic Film	4.86%	26.22%	1.28%
Textiles	3.18%	95.00%	3.02%
WEEE	1.22%	89.01%	1.09%
Sum	100%	-	68.78%

The report provided upper limits to the levels that different waste categories could be recycled and indicated that based on current materials in the waste stream up to almost 70% of household waste could be recycled, i.e. if each household was a super-committed recycler then local authority recycling rates for household waste would be close to 70%. Given that WRAP estimate that super-committed recyclers comprise 30% of households, then the actual level of recycling achieved is likely to be much less.

ENERGY CONTENT OF HOUSEHOLD WASTE

If complete combustion is assumed then the ‘useable’ energy released from MSW can be deduced according to combustion and exhaust gas temperatures (Themelis *et al.*, 2002a). The structure of MSW can be approximated as a hypothetical compound of the form $C_aH_bO_cN_dS_e$ (Tchobanoglous *et al.*, 1993; Tsiliyannis, 1999; Vidal *et al.*, 2001; Themelis *et al.*, 2002a; Themelis *et al.*, 2002b; Durmusoglu *et al.*, 2005; Chester *et al.*, 2008) and enthalpies of formation and combustion of naturally occurring organic compounds similar in structure can be used to deduce an approximate heating value for the hypothetical compound. This bond enthalpy method is useful if the waste stream is likely to remain constant in its composition, i.e. the structure of the hypothetical compound remains approximately the same, but under aggressive recycling scenarios this is unlikely to be the case. Moreover, knowledge is required of the thermal treatment technology to be employed and thus makes a generalised approach more difficult.

A modified Dulong formula can also be used to estimate the thermal content of waste streams. The advantage of this method is that it is based on carbon, hydrogen, oxygen, nitrogen, and sulphur content of the waste stream (Tchobanoglous *et al.*, 1993), data which is required to determine hypothetical compound structure. The Dulong formula is presented in Equation 1; the coefficients are determined from assumptions about how each element releases heat during combustion (Chang

et al., 2008). Hence in order to understand the effect that recycling will have on the CV of residual MSW, it necessary to know how recycling will affect chemical composition.

Equation 1

$$\text{Gross CV(MJ/kg)} = 0.337C + 1.418(H - \frac{1}{8}O) + 0.023N + 0.093S$$

Where the coefficients C, H, O, N, and S represent the percentage of carbon, hydrogen, oxygen, nitrogen and sulphur in the waste

Chemical Composition of UK Waste

The most comprehensive analysis of UK MSW was undertaken for the Welsh Assembly (Poll, 2003; Burnley *et al.*, 2007) but the chemical composition was not reported. In order to fill this gap in the literature, Chester *et al.* (2008) reviewed a number of UK waste surveys to provide upper and lower bounds to the chemical composition of reported waste streams. These data are summarised in Table 2.

Table 2: Typical Chemical Composition of Waste Fractions [Source: Chester *et al.* (2008)]

Category	Moisture	Mean Chemical content (percentage dry weight)					Ash
		C	H	O	N	S	
Paper	11.08%	45.94%	6.35%	38.55%	0.48%	0.21%	8.47%
Card	15.88%	44.85%	5.98%	43.38%	0.18%	0.20%	5.41%
Dense Plastic	7.50%	73.81%	11.90%	4.83%	0.25%	0.13%	9.09%
Plastic Film	4.50%	44.77%	6.08%	32.45%	1.74%	0.36%	14.60%
Textiles	14.49%	47.64%	6.30%	35.46%	3.04%	0.23%	7.33%
Combustibles	55.16%	45.35%	5.51%	32.45%	0.92%	0.37%	15.41%
Non-Combustibles	2.25%	0.50%	0.10%	0.40%	0.10%	0.00%	98.90%
Glass	13.00%	0.50%	0.10%	0.40%	0.10%	0.00%	98.90%
Ferrous Metal	66.38%	4.50%	0.60%	4.30%	0.10%	0.00%	90.50%
Non-Ferrous Metal	0.00%	4.50%	0.60%	4.30%	0.10%	0.00%	90.50%
WEEE	5.50%	0.50%	0.10%	0.40%	0.10%	0.00%	98.90%
Hazardous Household	6.25%	0.50%	0.10%	0.40%	0.10%	0.00%	98.90%
Garden waste	11.31%	43.62%	5.55%	33.92%	2.21%	0.32%	14.38%
Kitchen waste	7.04%	44.77%	6.08%	32.45%	1.74%	0.36%	14.60%
Fines	14.11%	26.30%	3.00%	2.00%	0.50%	0.20%	68.00%

Combining data from Table 1 and Table 2, a hypothetical compound of the form $C_aH_bO_cN_dS_e$ can be deduced. The first step is to determine the %dry waste of each fraction of the waste stream and then compute the amount of each element (C, H, O, N, and S) present in each waste fraction using ultimate analysis data. The calculated percentage of each element is then multiplied by the dry weight; this is repeated for each element in each waste fraction, including moisture (H_2O). Once the chemical composition of each waste fraction has been computed, the values for each element are then summed, divided by their molar mass and normalised with respect to the mass of sulphur, i.e. the subscript “e” is equal to one, and the hypothetical compound is thus deduced². The percentages of each element comprising the hypothetical compound can then be calculated and used in Equation 1 to estimate the CV of the waste stream.

² A more detailed explanation of the process can be found in Tchobanoglous *et al.* (1993).

QUANTIFYING RECYCLING POTENTIAL

If some assumptions are made about the percentages of waste recycled by each of WRAP's recycler categories then it is possible to analyse how recycling impacts household residual waste composition. Then, based on this composition, infer what effect recycling has on calorific value. WRAP report that non-recyclers have a recycling rate of 0% and super-committed recyclers recycle *a lot to 100%*, whereas, non-committed recyclers *recycle sporadically or just a little* and committed recyclers recycle *a little to a fair amount* (Pocock *et al.*, 2008). A study by Martin *et al* (2006) investigated the social cultural and structural influences on household waste recycling in Burnley, UK and identified 3 types of recyclers: non-recyclers who recycled no items and accounted for 17.5% of households; casual recyclers who recycled between 1 and 4 items and accounted for 55% of households; and full recyclers who recycled all 5 fractions collected for recycling and accounted for the remaining 27.5%. Crudely, this can be approximated to non-recyclers having a recycling rate of 0%, casual recyclers 20 to 80%, and full recyclers 100%.

Furthermore, a study by Barton *et al.* (2001) on recycling rates in Bradford identified that household recycling rates of various recyclable fractions (paper, card, textiles, plastics, glass, and metals) ranged from 29% to 76%. The study reported that prior to a recycling scheme being introduced 21% of households recycled less than 4 materials and only 10% of households recycled more than 9 materials. However, following the introduction of a recycling scheme only 1% of households recycled less than 4 materials and 52% of households recycled 9 or more materials. Based on these two sets of figures, the following recycling rates for each category of recycler identified by WRAP have been assumed:

- Non-recyclers: 0%
- Non-committed: 20% to 60%
- Committed: 60% to 90%
- Super-committed: 100%

Four scenarios were developed and analysed to explore the effect that recycling has on the chemical content of residual waste streams and, therefore, the calorific value:

- a business as usual (BAU) case using the current recycling rates of each category;
- a behaviour shift scenario explored the effect on recycling rate if each household 'moved up' a recycling category;
- a worst case scenario in which each household is a non-recycler;
- a best case scenario in which each household becomes a super-committed recycler.

Dealing with the uncertainty

Monte Carlo simulation provides a method of estimating the expected value of a function by taking an average value of that function over a large number of trials (Ross, 2000). The function's parameters are assigned probability distributions to represent their uncertainty, which can then be used to estimate the uncertainty of the function itself. Monte Carlo simulations were used to estimate parametric uncertainty in the chemical composition and CV due to:

- an arbitrarily assigned tolerance of 10% either side of the values reported by FOE and WRAP, and were modelled as a uniform distributions;
- assumed minimum and maximum percentages of waste recycled by each recycler-type and were assigned uniform distributions;
- the minimum, maximum, and typical values of each fraction in the household waste stream (taken from Chester *et al.* (2008)), which were modelled as triangular distributions.

Mean waste composition and capture rates estimated from the simulation are reported in Table 3.

Table 3: Household Waste Composition and Capture Rates [Source: Chester et al. (2008); FOE (2007)]

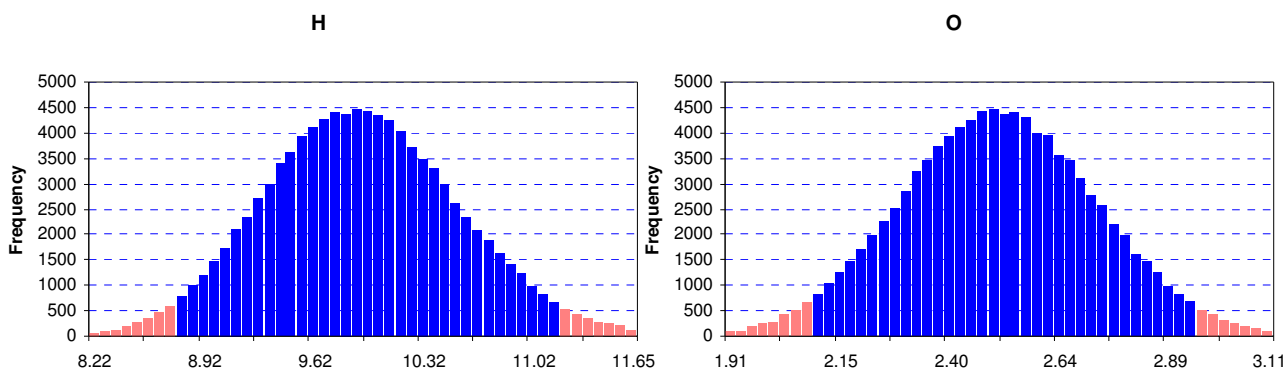
Waste Category	Typical % wt	Maximum Capture Rate for each Waste Fraction					
		BAU		Behaviour Shift		Best Case	
		Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
Paper	16.28%	42.32%	3.57%	54.64%	3.70%	59.67%	2.61%
Card	8.81%	51.23%	4.74%	66.16%	5.15%	72.27%	4.19%
Dense Plastics	6.24%	31.34%	2.59%	40.47%	2.67%	44.20%	1.81%
Plastic Film	4.86%	18.41%	1.52%	23.77%	1.57%	25.96%	1.06%
Textiles	3.18%	65.11%	5.54%	84.08%	5.79%	91.83%	4.17%
Combustibles	6.80%	21.19%	1.65%	27.36%	1.64%	29.88%	0.90%
Non-combustibles	2.01%	40.40%	3.51%	52.17%	3.71%	56.98%	2.78%
Glass	6.76%	52.64%	4.88%	67.97%	5.26%	74.25%	4.30%
Ferrous	2.63%	54.75%	4.62%	70.71%	4.81%	77.22%	3.43%
Non-ferrous	1.20%	54.76%	4.54%	70.71%	4.68%	77.21%	3.18%
WEEE	1.22%	62.47%	5.18%	80.69%	5.34%	88.13%	3.65%
Hazardous	0.44%	4.48%	0.42%	5.79%	0.47%	6.33%	0.39%
Garden Waste	10.18%	63.17%	5.83%	81.58%	6.33%	89.07%	5.18%
Kitchen Waste	25.98%	58.87%	5.46%	76.02%	5.92%	83.05%	4.82%
Fines	2.65%	56.16%	5.20%	72.51%	5.63%	79.17%	4.59%
Misc.	0.73%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Total	100.00%	49.42%	5.51%	63.81%	6.38%	69.70%	5.92%

Variation in chemical composition

The capture rates for the business as usual and best case scenarios were used in a Monte Carlo simulation to explore the likely effect that the recycling rates would have on the chemical composition of household residuals by analysing how the structure of a hypothetical compound changes in each scenario. It is convenient to consider a hypothetical compound structure of the form $C_6H_aO_b$ for two reasons. Firstly, that the principal components of combustion are carbon, hydrogen, and oxygen; and secondly that 25% of the waste is paper and card (cellulose based, i.e. $C_6H_{10}O_5$) and a further 35% is putrescibles (food and garden waste, i.e. $C_6H_{10}O_4$ (Themelis *et al.*, 2002b)). The hydrogen and oxygen content under the BAU scenario are presented in Figure 1 and under the Best Case scenario in Figure 2. Because Monte Carlo simulations arise as a consequence of the strong law of large numbers (Ross, 2000), if the number of trials in the simulation is sufficiently large enough then the Central Limit Theorem dictates that the expected value of each function will be approximately normally distributed (Hsu, 1997).

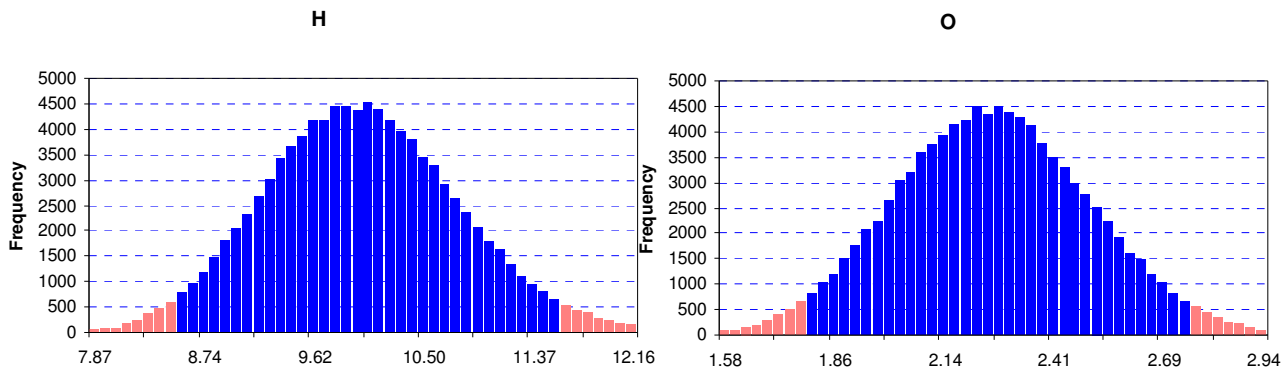
For the BAU scenario (Figure 1), the hydrogen content had a mean of 9.93 and the standard deviation was 0.63, hence the 95% confidence interval (shaded in blue) lies between 8.76 and 11.22. For the oxygen content the mean was 2.51 and the standard deviation was 0.22, hence the 95% confidence interval lies between 2.08 and 2.94. Therefore, the number of moles of oxygen varies from 2 to 3 and moles of hydrogen from 9 to 11.

Figure 1: Frequency Distribution of Hydrogen and Oxygen Content under the BAU Scenario



For the Best Case scenario (Figure 2), the hydrogen content had a mean of 10.02 and the standard deviation was 0.78, hence the 95% confidence interval (shaded in blue) lies between 8.56 and 11.63. For the oxygen content the mean was 2.26 and the standard deviation was 0.25, hence the 95% confidence interval lies between 1.79 and 2.76. Therefore, the number of moles of oxygen varies from 2 to 3 and moles of hydrogen from 9 to 11.

Figure 2: Frequency Distribution of Hydrogen and Oxygen Content under the Best Case Scenario

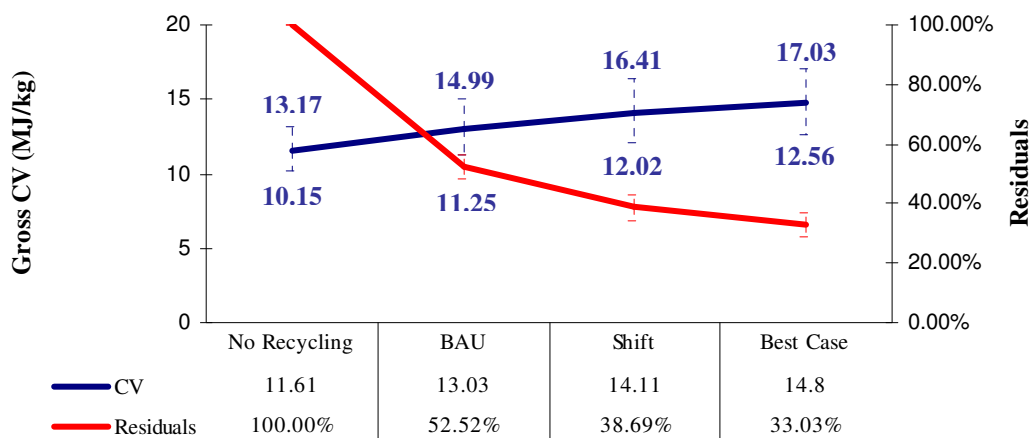


Variation of Calorific Value

The capture rates for each scenario were used in another Monte Carlo Simulation to explore how the CV changed. As CV is calculated per kg of waste, the mass of the residuals was also included to keep the results of the analysis in context. The results of the simulation are summarised in Figure 3; the error bars indicate the 95% confidence interval for the CV and residuals in each scenario. As recycling potential improves the CV increases because the relative proportion of plastics increases. However, there is a trade-off: as the CV increases the quantity of residuals decreases at a much greater rate such that a much larger ‘catchment area’ would be required to meet a facility’s operational capacity.

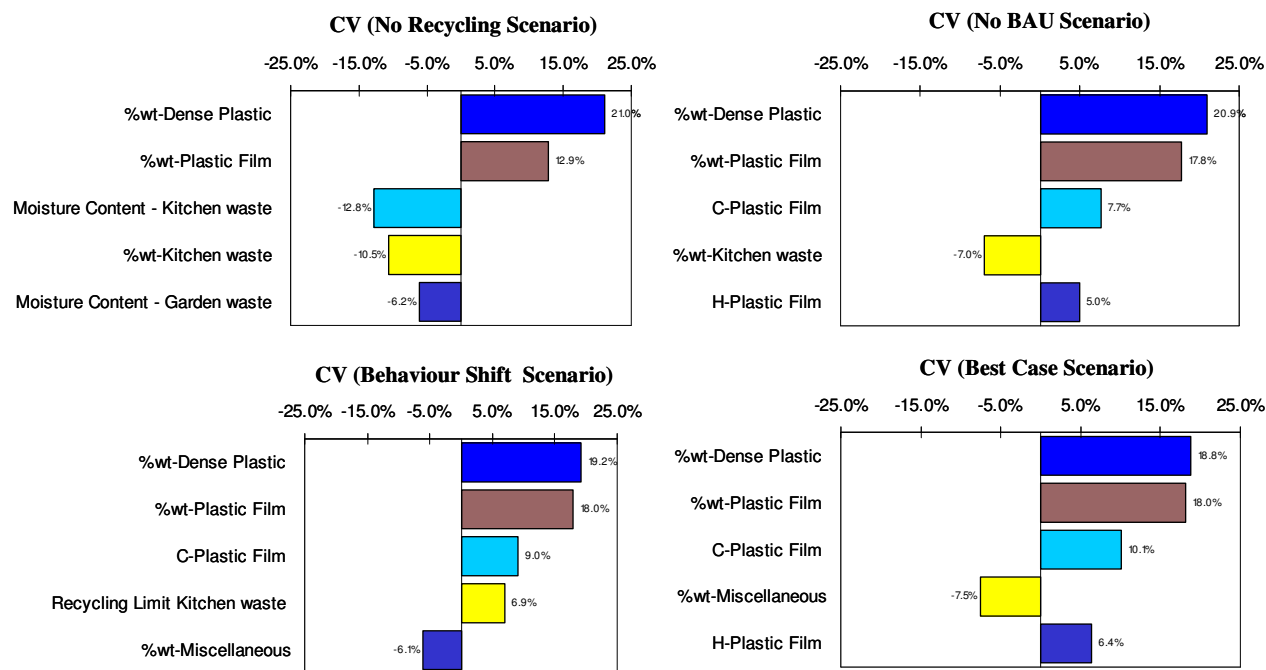
The widths of the confidence intervals associated with the CV in each scenario are fairly large, indicating that the parametric uncertainty introduces considerable variation in the CV. The parameters that make a significant contribution to the width of the confidence intervals are shown in Figure 4; those parameters shown as making a positive contribution to the variance have a ‘proportional relationship’ to the CV, i.e. an increase in that parameter leads to an increase in the CV and those shown as making a negative contribution have an ‘inversely proportional relationship’ to the CV.

Figure 3: Effect of Recycling Scenarios on CV and Quantity of Residuals



The dominant parameters in the no recycling scenario are putrescibles and plastics; in particular the moisture content of the putrescible streams tends to reduce the CV. Plastics tend to dominate the variance of CV in all scenarios, but this should be expected. The plastic streams have one of the lowest recycling limits yet one of the highest relative CVs in the waste stream. Hence as plastic begins to dominate the residual stream it will have a greater influence on the CV. With the exception of kitchen waste in the shift scenario, all other dominant parameters are related to the physical and chemical composition of the waste stream rather than the arbitrary limits applied to the recycling potentials. This indicates the importance of understanding the composition of waste entering a thermal treatment plant: being able to reduce the uncertainty in %weight of the plastics fractions would reduce the uncertainty associated with CV of the waste.

Figure 4: Contribution to the Variance in CV of the Residual MSW in each Scenario



DISCUSSION

While the range of participation rates of each recycler category has been assigned with a certain degree of subjectiveness, it has provided an indicative feel to how the chemical composition of the residuals is influenced by recycling. This analysis suggests that the chemical composition is fairly constant, but this should be expected as a large majority of the fractions recycled contain very little C, H, or O (e.g. metals, WEEE, glass) so the underlying chemical composition should remain broadly constant. However, the results do show that the oxygen content reduces as recycling participation increases, which should also be expected because oxygenated compounds, such as paper, card, kitchen waste, etc. have higher recycling limits than plastics. Furthermore, plastics have very low oxygen content so as their relative proportion increases, oxygen content in the waste should decrease. Hence the calorific value of waste should improve because of the increased plastic concentration; the analysis of CV using a modified Dulong formula reinforced this point.

The sensitivity charts (Figure 4) indicate that removing kitchen waste will increase the CV of the residual stream and improve the efficiency of thermal treatment, a result which is in agreement with the analysis of New York City MSW undertaken by Themelis et al. (2002a). In general, separate putrescibles collection adds value to a waste management system because the biowaste is eligible for PAS 100 accreditation. For the thermal treatment plant owner, separate collection means that there is less moisture to drive off during the treatment process so there should be less of an energy penalty associated with using residual household waste as fuel.

Although increased recycling participation does seem likely to increase the thermal content of the residuals such that more energy could be generated per tonne, this may not be that beneficial to owners of thermal treatment plant. Firstly, higher proportions of plastic means that more of the energy comes from a fossilised source so the ROC-able content of the waste will reduce (HMSO, 2009) along with its associated revenue streams. And secondly, the reduction in quantity of residuals is likely to make the market place more competitive as firms will be competing over a smaller share of the waste.

In the Best Case scenario, 33% of the waste still requires treatment and disposal. The solutions to managing this waste may be very different in rural locations when compared to higher density areas where the tonnages generated maybe large enough for typical sized plant to be viable. The rural areas may require the residuals to be transported long distances or a change in strategy to micro-level solutions.

However, the fact that only 67% of waste can be recycled indicates that the current approach to developing technologies to treat and recover waste sustainably is, perhaps, entirely wrong. The focus should be to identify the reasons why a third of the waste cannot be recycled and, rather than trying to develop markets for such products, the problem should be tackled at source. Householders can only generate waste from the goods and services that they purchase and they are therefore limited to how much recyclable packaging they can generate. It is also unfair on the householder to subsidise the collection and treatment of waste materials when they are not wholly responsible for the burden such materials place on the environment. It is more reasonable for the *producer pays* principle to be applied to manufacturers because they are actually *producing* the waste, albeit disguised as packaging.

Ramifications for UK Plc

Figure 4 also highlights that plastics in the residuals essentially control the CV. But this is a consequence of the limited recycling opportunities for some plastics identified by FOE (2007). The development of markets in the future or the outlawing of plastics with little or no recycling potential would seriously compromise any thermal treatment plant designed to process residual waste. Hence, encouraging such technologies via the Renewables Obligation Order has the potential to disincentivise any improvements to the recycling potential of individual waste fractions. But this should come as no surprise when considering the carbon footprint from managing residuals.

Recycling provides carbon benefits that are generally not counted on the UK's carbon balance sheet as the offsets occur in other countries (Fisher *et al.*, 2006). Whereas generating electricity from waste directly offsets emissions from fossil fuel fired power stations in the UK, which would appear on the carbon balance sheet. But if benefits from sequestering carbon could be quantified, a better solution would be to landfill the residuals if the recycling levels of the Best Case scenario were reached, because of the amount of plastics present in the residual stream. The carbon in the plastics would be sequestered rather than being realised into the atmosphere as fossilised CO₂.

CONCLUSION

The mean value of the CV rises from 12 to 15 MJ/kg as recycling effort improves; hence new build EfW plant will need combustion technologies that can cope with this possible variation in CV if recycling rates improves in the future. However, the ROC-able content is likely to reduce if recycling increases because of the current limits to recycling plastic fractions: there is no free lunch.

Biowaste content is a dominant parameter and its removal from the residual stream significantly improves the CV. Therefore, regions of the UK that employ a separate organics collection strategy may be more suitable for the location of EfW plant.

Removal of recyclables reduces the mass of residuals considerably. The Best Case Scenario could see 70% of household waste recycled, which suggests that EfW plant might be better suited in locations close to large urban areas to ensure adequate throughput of feedstock. However, an underlying message is that perhaps those materials that cannot be recycled should not be used in manufacturing processes.

Regardless of the recycling potential of the public, householders can only generate waste from the products that they purchase. Therefore, rather than the 'existing end of pipe' approach to waste recovery, the onus should be on the manufacturer to change their ethos and supply products that can be managed sustainably.

ACKNOWLEDGEMENTS

This research was sponsored by Biffa Waste Services with specific assistance from D Savory and the operational staff in his team. Additional funding and support was provided by ATCO Power and in particular the author extends his gratitude to M Lees, G Paling, and R Hodgson for their valuable contributions to this work. The author also wishes to thank Professor D Stupples of City University for his guidance and patience throughout the research and J Barton of the University of Leeds for his comments and insight during the preparation of this paper.

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