Programme Area: Bioenergy

Project: Energy From Waste

Title: Final Waste Assessment

Abstract:

This deliverable is number 3 of 3 in Work Package 1 and presents the results of the assessment of UK waste arisings. The findings are drawn from a waste sampling regime carried out by Cranfield University across a number of physical waste collection sites, together with analysis of data from a number of sources. This report builds on its predecessor D1.2 in that it presents the conclusions of the analysis of waste undertaken for the period November 2009 to September 2010. The aim of this final deliverable is to provide an understanding of the UK waste arisings, the composition of these materials and the energy potential of available wastes.

Context:

The Energy from Waste project was instrumental in identifying the potential near-term value of demonstrating integrated advanced thermal (gasification) systems for energy from waste at the community scale. Coupled with our analysis of the wider energy system, which identified gasification of wastes and biomass as a scenario-resilient technology, the ETI decided to commission the Waste Gasification Demonstration project. Phase 1 of the Waste Gasification project commissioned three companies to produce FEED Studies and business plans for a waste gasification with gas clean up to power plant. The ETI is taking forward one of these designs to the demonstration stage - investing in a 1.5MWe plant near Wednesbury. More information on the project is available on the ETI website. The ETI is publishing the outputs from the Energy from Waste projects as background to the Waste Gasification project. However, these reports were written in 2011 and shouldn't be interpreted as the latest view of the energy from waste sector. Readers are encouraged to review the more recent insight papers published by the ETI, available here: http://www.eti.co.uk/insights

Final Waste Assessment

Report 1.3

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Executive Summary

This report is the final deliverable of work package 1, which is one of four work packages within the energy from waste project funded by the Energy Technologies Institute [ETI]. This is a flexible research project [FRP] and this deliverable presents the results of waste sampling, including physical composition of waste materials and the detailed laboratory analysis. The conclusions of the analysis undertaken for the period of November 2009 to September 2010 are presented in this report. The aim of this work package was to provide an understanding of the UK waste arisings, the composition of these materials and the energy potential of available wastes.

The MSW and C&I mixed waste streams consist of large amounts of different components which have the potential for energy recovery, such as paper, card, plastics, organics [food and green waste] and textiles. C&D waste consists largely of soils and aggregates, which are inert materials of no energy value.

The findings show that up to 70% of C&D wastes by weight is inert, which is material that is not biodegradable and of no energy value. The C&I wastes were observed to contain higher quantities of paper and card than MSW, which is due to the differences between the recycling targets and policies relating to these two waste streams. The C&I and MSW materials both contained large quantities of film plastic, which yielded the highest CV of all components analysed [39,000 kJ/kg].

The potentially recyclable materials present in the residual wastes, in particular C&I, is of importance. The plastic materials contribute significantly to the CV of the overall material, and as the proportion of these materials are policy and economically driven, being able to understand future recycling trends would be important. The economics of recycling plastics or recovering energy from these materials has been compared. It was concluded that where both heat and electricity is recovered and exported it is economically favourable (due to the increase in overall efficiency) to recover the energy, however where only electricity is recovered in a typical incinerator (e.g. moving grate) facility it is more economically favourable to recycle the plastic. However many recyclable materials, such as plastics and paper, cannot be continuously recycled due to the degradation and/or contamination of the materials as they are reprocessed. As a result, there will always be 'recyclable' materials within the residual stream. To achieve higher recycling rates (ca. 70%) for the C&I waste stream then approximately 90% of the paper, card, dense plastics, glass and metals will need to be removed from the residual C&I stream. Recycling cannot be the complete solution, but will remain for as long as it is practically and economically viable to do so. The environmental impacts of recycling and/or energy from waste is recognised as important, and further work is required to enhance the current understanding, alongside a review of existing data.

An innovative image analysis tool was developed as part of this project. This has shown potential as an alternative method of monitoring waste composition. Additionally analytical methods developed at Cranfield University could be utilised in understanding the biogenic carbon content of heterogeneous waste materials, which is useful for the allocation of renewable obligation certificates [ROCs].

Contents

Cranfield UNIVERSITY

Figures and Tables

Glossary

CA- Civic amenity site [a site which contains bins for residual and recycling waste materials by which the public can dispose of household waste.]

C&D- Construction and Demolition

C&I- Commercial and Industrial

CV- Calorific Value [a measure of energy content]

DM- Dry matter [% of a sample that is not moisture (BS EN12879:2000)]

EfW- Energy from Waste. The process of generating energy, electricity and/or heat, from waste-derived materials.

ETI- Energy Technology Institute

HHW- hazardous household waste [batteries, engine oil, paint etc]

HS- Hand sorting; sorting of waste by hand to determine the physical composition.

HWRC- Household waste Recycling Centres [as CA]

IA- Image analysis; determination of the physical composition of waste from images.

LOI- Loss-on-ignition [% of a sample that is determined to be organic under a controlled laboratory test (BS EN12879:2000)]

MSW- Municipal Solid Waste

RDF [refuse derived fuel]- a high calorific material obtained from the processing of mixed organic wastes. Consists largely of paper, card and plastics.

Recyclate- a recycled material

Recycling- the separation of waste materials either at source or at a bulking centre where materials are then diverted for treatment prior to reuse as a raw material commodity.

Residual wastes- typically black bag waste; what is left after recycling

SRF [Solid Recovered Fuel]- similar to RDF except produced to a set standard and classified in terms of CV, chlorine and mercury content.

Waste composition- the percentage by weight of plastics, wood, paper, etc.

Waste arisings- the quantity [tonnes] and type of waste being produced at a given location(s) within a specified time period

WEEE- waste electronic and electrical equipment

1. Introduction

Work package 1 aims to collect the available data on waste arisings and composition within the UK to then convert this in to a value of its fuel potential. This work draws information from a review of completed and ongoing waste studies plus a sampling programme of waste from UK sites. Expert advice has been sought from the Defra Waste Research and Evidence team in addition to input from the UK waste industry and process operators to guide the research design. Data has been drawn from a wide range of sources. In addition Shanks Waste Solutions Ltd. have provided access to their sites, company data and site specific samples and data.

There is a requirement to understand the arisings and composition of all wastes in the UK in order to understand the energy recovery potential of these materials. Report 1.1 and the associated AEA Technology waste flow models highlighted the available data and identified the areas in which the data and level of understanding was limited; the waste streams which were not well understood were commercial and industrial [C&I] and construction and demolition [C&D]. A sampling strategy was developed to focus more on areas of lower understanding, but high energy potential. Therefore the waste sampling and site data collection was prioritised on C&I wastes as these represent the arisings with the highest volume matched by highest calorific value where least information is known.

Report 1.2 presented the initial findings, including that up to 70% of C&D wastes by weight is inert, which is material that is not biodegradable and is of no energy value.   The C&I wastes were observed to contain higher quantities of paper and card than MSW, which is due partially to the differences between the recycling targets and policies relating to these two waste streams. However as businesses are likely to be generating wastes which consist largely of paper and card, such as wastes arising from offices (paper) and retail (packaging material), it is likely that some of these materials are included in the residual collections.

A summary of UK waste arisings is given in Table 1.

		England			N.Ireland	Scotland	Wales
		02/03.[1]	06/07.[2]	08/09.[1]	06/07.[2]	06/07.[2]	06/07.[2]
C&I	**Total ['000 t]**	67,900	58,658	48,018	1,560	8,093	3,573
	% Recycled		48.7	52.0	52.3	46.0	57.5
MSW	**Total ['000 t]**		29,144	27,333	1,053	2,134	1,785
	% Recycled		30.9	37.6	29.0	30.0	34.0
C&D	**Total ['000 t]**		89,600		1,715	11,804	12,167
Agricultural	**Total ['000 t]**		2,590		28	370	32

Table 1. Summary of UK waste arisings for each waste type. [[1]AEA models, [2](Defra. 2010)]

This report provides the results of a complete waste composition study spanning four seasons across various sites in the UK. The development of an innovative image analysis technique is presented and discussed, as is a focused study of the arisings of plastic types in the mixed C&I waste stream.

Data, such as arisings and composition, was drawn from 5x main sources including peer reviewed references, sector reports, industry specific data, operator data [Shanks] and direct sampling. These are highlighted in Figure 1. The specific Shanks sites were chosen as these represent a typical mixed waste material, and so provide an insight into the content of mixed residuals, and provide access to a wide variety of waste stream-specific data.

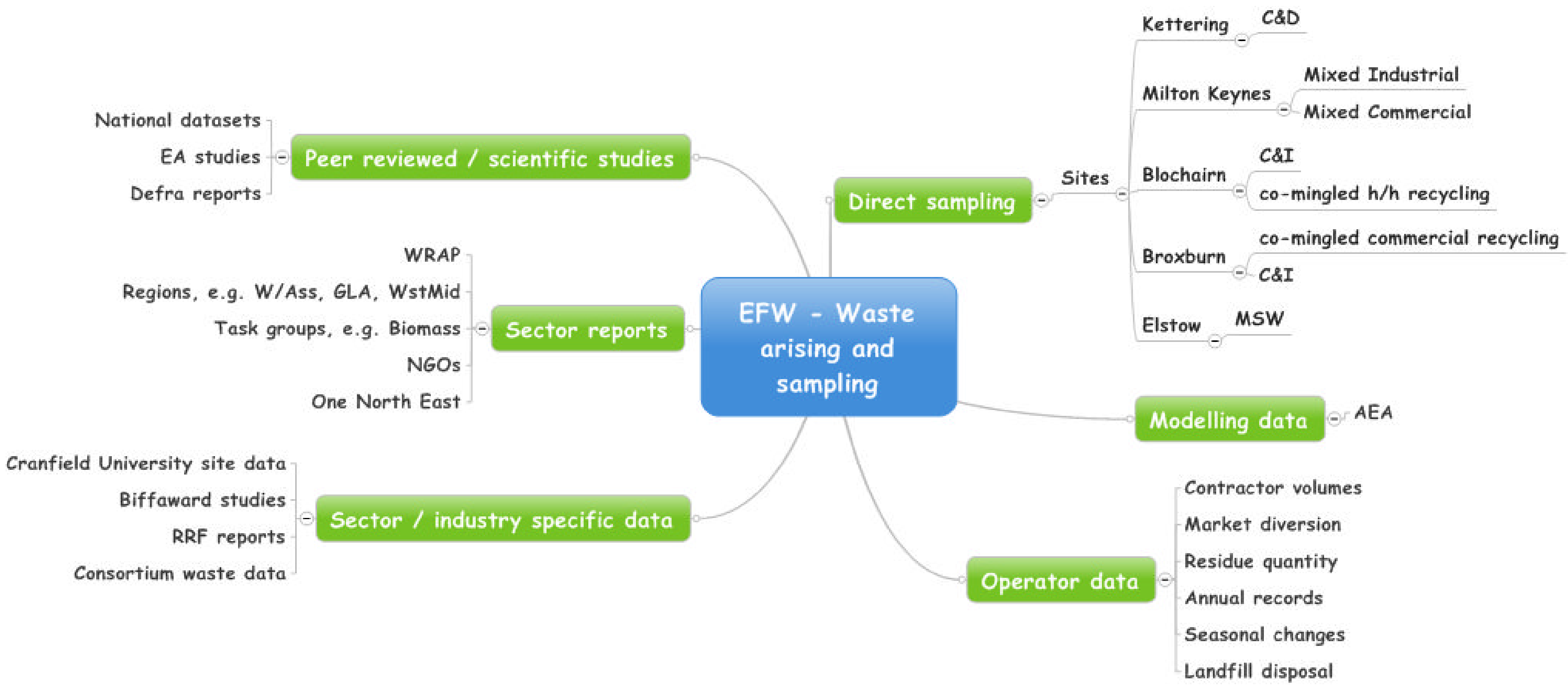

Figure 1. Data sources in WP.1

The objective of this work-package was to gain the best possible understanding of the energy potential of wastes, biochemical and/or thermo-chemical, across the UK. This information will then be used within the project to specify better the technology requirements for using waste as a fuel. In order to achieve this, the research method will extend the value of existing data to understand the properties of waste as a fuel. This is over and above the evidence collated for UK policy and regulatory development. It will then be used to guide the technology assessment and development priorities in the following work packages. Central to this is maximising the reliability of results to inform best value in monitoring and the later decisions within the technology assessment.

2. Aims and Objectives

2.1. Aims

This work package aims to collate UK waste data from a number of sources, identify knowledge limitations and produce new data which enhances our understanding of UK wastes. The improved understanding of the wastes will subsequently allow the overall ETI project objectives to be met, which are to identify the next generation of technologies which can be used to generate energy from a wide variety of available waste materials.

2.2. Report requirements

It has been agreed previously that this report will provide-

- An executive summary
- Summary of waste data in initial waste assessment report (1.2)
- Description of waste compositional and chemical analysis techniques employed
- Raw data collected
- Final results for main energetic and volumetric data for assessed wastes
- Discussion of collected data in relation to existing data identified in 1.1
- Final conclusions of UK energy containing waste arisings

3. Methods

Waste samples were taken from Shanks sites in England and Scotland [Figure 1], and have focused mainly on the C&I waste stream due to the lack of understanding. As outlined in Report 1.1 Volume 1, the sampling strategy was developed to suit the knowledge gaps. The Shanks site in Milton Keynes typically receives commercial and industrial streams separately, and so this site equals 4 visits [2 visits per season; 2 sets of sample per visit]. Therefore a total of 12 site data sets per season was expected.

The seasons of this project are:

- Season 1 covers the period of November 2009 to January 2010;
- Season 2 covers the period of February to May 2010;
- Season 3 from end of May 2010 to July 2010;
- Season 4 covers September 2010.

For each site visit a detailed hand sort of the waste was carried out, along with 30 images for visual composition analysis. For each detailed sort there was at least 1 representative sample sent to an external lab for proximate and ultimate analysis to determine properties such as moisture content, calorific value and elemental composition as detailed later. Each sample was conducted in the following steps:

- 3x bucket loads from input waste material;
- Bags split and waste spread evenly- ≤50m^3 spread
    - 30x images for subsequent analysis
- 10-15x shovel loads of above spread for detailed sort- ~30-60kg [sub-set]
    - C&D materials typically ≥100kg;
    - Observations recorded for large/abundant/unusual items and a visual description of moisture content;
    - Photographs taken of site during sampling.
- Representative sample made up for lab analysis
    - From compositional analysis for site (mixed waste stream);
    - Single material samples, e.g. paper, card, plastics

3.1. Physical composition

The waste material, following the preparation as described previously, was then hand sorted into individual categories such as-

- Paper;
- Card;
- Dense plastics;
- Film plastics;
- Wood;
- Organics and fines;
- Inert materials ;
- Metals;
- Glass;
- Miscellaneous combustibles;
- Textiles ;
- Waste electronics and electrical equipment [WEEE]

In addition, the work benefitted fro an associated MSc project which examined the prevalence of specific plastic types in mixed C&I waste streams. The plastics separated from the C&I waste materials from selected sites were sorted into specific plastic types, such as-

- High density polyethylene [HDPE];
- Low density polyethylene [LDPE];
- Polypropylene [PP];
- Polyvinyl chloride [PVC];
- Polyethylene terephthalate [PET];
- Unidentified non-recyclable plastics;
- Plastic film ;
- Polycarbonate

3.2. Image analysis

The development of the image analysis technique was part of a Masters level research project undertaken at Cranfield University, further details are provided in Appendices B and D.

The Image Analysis (IA) procedure consisted in the following two steps:

- Image pre-processing;
- Dot-grid analysis;

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The area of each category was determined using a dot grid. Therefore, IA was preceded by an initial study where the dot grid resolution was defined. A dot-grid was super-imposed onto the corrected image, and the area of each category per each image selected was measured by manually counting the dots touched. The results of the IA data were then compared with hand-sort (HS) data, to assess the accuracy of the image analysis technique. Further detail on the image analysis method is provided in Appendix B.

3.3. Proximate and ultimate analysis

For proximate and ultimate analysis of the mixed waste streams, a sample of around 10 kg was sent to the third-party laboratory. This sample was dried at 105°C to determine the moisture content. The dried sample was then ground to <10 mm. A fraction of this homogenised material was then ground further to <1 mm for proximate and ultimate analysis.

The lab analysis comprises of proximate and ultimate analysis, as shown in Table 2.

Method	Parameter	Principle of method
Moisture content [CEN/TS 15414]	Total Moisture %	A known mass of sample is dried at a nominal temperature of 105°C in an air atmosphere until constant mass is achieved and percentage moisture calculated from the loss in mass.
Ash content [CEN/TS 15403]	Ash %	A known mass of the sample is heated in air to 550ºC +/- 10 in 60 minutes and is kept at this temperature for a minimum of an additional 120 mins. The ash content is determined from the mass of residue remaining after incineration
Volatile matter [CEN/TS 15402]	Volatile Matter %	A known mass of sample is heated at 900ºC, out of contact with air for 7 minutes +/- 5 seconds. The volatile matter is calculated from the loss in mass of the sample. A deduction is made for the loss in mass due to moisture.
Gross and net CV [CEN/TS 15400]	Gross and Net Calorific Value kJ/kg	A known mass of sample is burnt in oxygen-enriched atmosphere within the calorimeter bomb. The heat released increases the temperature of the bomb and its surrounding water jacket. The calorimeter measures the temperature rise, makes the necessary corrections, calculates the heat release attributable to the combustion of the sample, and reports it as the calorific value of the sample in kJ per kg
Carbon [CEN/TS 15407]	Carbon %	A known mass of sample is burnt in oxygen. The combustion gases are passed over suitable reagents to assure complete oxidation and removal of undesirable by-products such as sulphur, phosphorus and halogen gases. The oxides of nitrogen are converted to molecular nitrogen and residual oxygen is removed in the reduction tube. The concentrations of carbon dioxide, water vapour and nitrogen gas are measured by thermal conductivity cells. The instrument uses the concentration of these gases together with the sample weight to give a direct readout of the percentages of carbon, hydrogen and nitrogen.
Hydrogen [CEN/TS 15407]	Hydrogen %	
Nitrogen [CEN/TS 15407]	Nitrogen %	
Oxygen [by difference]	Oxygen %	Oxygen content is calculated by difference, i.e. 100- ∑%C+%H + %N
Sulphur [CEN/TS 15407]	Sulphur %	A known mass of sample is incinerated at 1350ºC in an oxygen- enriched atmosphere. The sulphur in the sample is converted to sulphur dioxide and is measured by an infrared cell. The measured quantity is converted into a percentage
Chlorine [CEN/TS 15408]	Chlorine %	A known mass of the sample is oxidized by combustion in a bomb containing oxygen under pressure. Chlorine-containing compounds are converted to chlorides which are absorbed and/or dissolved in an absorption solution (water or KOH 0,2 M solution); analysis of Cl by ion chromatography

Table 2. Proximate and ultimate analysis

Along with the mixed waste materials and the individual components of waste, the above lab analysis will also be applied to other materials of potential interest from the waste sites. These typically included street sweepings, fines and light materials.

4. Results & Discussion

4.1. Physical composition

The average composition and analytical data for C&I waste materials assessed throughout the project is shown in Table 3. The ultimate analysis has been adjusted to a dry basis in all tables. The compositional and analytical data for non-C&I wastes assessed as part of the project are shown in Table 4.

		Season					Net CV
		1	2	3	4	Average	[MJ/kg]
Physical Composition (% weight)	Paper	16.5	11.0	23.5	27.4	19.6	14.4
	Card	15.0	17.9	12.0	15.0	15.0	14.8
	Wood	16.1	19.5	6.8	4.8	11.8	16
	Metals	7.6	3.0	2.7	2.3	3.9	0
	Glass	3.0	1.2	1.7	0.9	1.7	0
	WEEE	0.7	0.1	0.3	0.9	0.5	0
	Textiles	2.8	8.7	7.4	2.1	5.2	20.7
	Dense Plastics	10.4	8.2	11.2	12.6	10.6	35.2
	Plastic Film	10.4	11.0	14.1	21.0	14.1	41.3
	Organic Fines	14.8	15.3	17.2	8.6	14.0	8.1
	Inert/Agg/Soils	2.8	1.4	1.5	1.8	1.9	0
	Misc. Comb		2.8	1.6	2.6	2.3	10
Proximate	Total Moisture %	40.1	17.6	16.5	10.0	21.1	
	Ash %	13.4	9.1	7.3	16.0	11.4	
	Volatile Matter %	41.7	60.4	70.3	69.1	60.4	
	Gross Calorific Value kJ/kg	8,306	11,850	18,365	18,543	14,380	
	Net Calorific Value kJ/kg	5,796	8,707	17,070	14,644	11,374	
Ultimate elemental analysis (%)	Carbon %	52.0	41.5	54.1	56.6	51.1	
	Hydrogen %	6.5	4.3	2.8	0.4	3.5	
	Nitrogen %	0.8	1.2	0.6	0.2	0.7	
	Oxygen %	40.3	52.6	42.3	42.2	44.4	
	Sulphur %	0.2	0.2	0.1	0.2	0.2	
	Chlorine %	0.2	0.2	0.1	0.4	0.2	
	Sample count	6	4	5	5		

Table 3. Average properties of C&I wastes for each season of WP1.

The paper and wood content of the mixed C&I waste show a sudden change between seasons 1 and 4. The reasons for this is not seasonal, rather a change in the sorting practices at specific sites. In seasons 1 and 2 the C&I waste at the Milton Keynes site was collected and stored separately, in that commercial wastes and industrial wastes were kept apart. The industrial wastes contained large quantities of wood waste, often in the form of pallets. The commercial wastes were found to contain more paper than the industrial stream, and also significantly less wood. From season 3 the commercial and industrial wastes were combined at the Milton Keynes site, and so the aggregated composition changed accordingly.

		Season 1			Season 2				Season 3		Season 4
	Site-	Blochairn	Broxburn	Kettering	Elstow	Elstow	Kettering	Kettering	Elstow	Kettering	Kettering
	Sample type-	Co-mingled hh recycling	Mixed commercial recycling	C&D	MSW (general)	MSW (general)	C&D	C&D	MSW	C&D	C&D
	Date-	08/12/2009	04/01/2010	25/11/2009	25/02/2010	17/03/2010	18/03/10	04/05/10	10/07/2010	15/06/2010	15/09/2010
Physical Composition (% weight)	Paper	50.3	40.3	3.9	4.7	12.7	0.1	0.0	8.4	0.0	0.0
	Card	20.0	27.7	2.8	3.0	2.1	5.3	0.0	14.0	0.0	0.3
	Wood	0.0	0.0	17.7	2.7	0.3	39.4	14.3	7.0	13.8	17.4
	Metals	3.4	1.3	4.1	6.4	1.2	2.1	2.0	7.0	0.5	0.0
	Glass	3.5	0.0	0.0	5.7	4.4	0.1	4.0	3.5	0.0	0.0
	WEEE	0.0	0.0	1.7	5.1	0.0	0.0	0.0	0.0	0.0	0.0
	Textiles	4.3	0.0	0.3	7.1	11.5	4.1	0.0	3.5	3.3	0.9
	Dense Plastics	12.3	12.7	1.8	14.5	3.6	5.5	11.6	7.0	3.1	3.0
	Plastic Film	1.4	14.2	2.5	19.9	18.0	4.2	0.0	7.0	1.5	0.4
	Organic Fines	4.9	3.9	0.0	22.2	37.0	0.0	0.0	28.0	0.3	0.0
	Inert/Agg/Soils	0.0	0.0	65.1	0.0	0.0	39.2	66.1	3.5	74.1	78.0
	Misc. Comb				8.8	9.2	0.0	2.0	11.2	3.3	0.0
Proximate	Total Moisture %	38.7	24.6	26.7	53.4	40.9	11.5	17.4	28.0	22.5	20.6
	Ash %	15.2	14.6	5	9.3	12.5	53.2	37.2	11.3	14.5	29.6
	Volatile Matter %	42.6	58.6	58.7	33.1	40	35.2	44.9	48.2	58.4	45.9
	Gross Calorific Value kJ/kg	8,504	11,295	3,798	6,205	10,167	4,592	2,497	18,858	5,541	2,752
	Net Calorific Value kJ/kg	5,549	7,119	3,030	4,541	8,443	3,859	2,320	14,681	5,152	2,520
Ultimate	Carbon %	50.99	50.54	46.86	49.51	49.50	39.15	17.20	66.00	55.99	56.40
	Hydrogen %	5.93	6.22	5.83	6.10	6.13	4.05	0.40	4.06	2.79	0.25
	Nitrogen %	0.45	0.33	0.31	0.75	2.09	1.88	2.50	0.43	0.55	0.2
	Oxygen %	42.45	42.76	46.78	43.33	41.32	52.28	78.40	29.31	40.47	42.9
	Sulphur %	0.09	0.08	0.09	0.19	0.28	1.91	0.50	0.10	0.10	0.2
	Chlorine %	0.09	0.07	0.13	0.13	0.68	0.73	1.00	0.10	0.10	0.2

Table 4. Composition and detailed analysis of non-C&I waste materials

The potentially recyclable content of mixed waste materials, MSW and C&I, was quite high. The paper observed in the C&I wastes was mostly office paper and newspaper, with the remainder consisting of tissue and packaging. There are varying quantities of drinks bottles, which were included in the dense plastic category; these are perhaps the easiest material to recycle currently within the residual waste streams.

It is anticipated, and shown in the AEA models used throughout WP1, that paper, card, dense plastics, glass and metals will predominantly contribute to higher recycling rates in 2050. Around 90% of each from the forecasted total residual arisings will need to be removed from the residual C&I stream in order to meet total C&I recycling targets of 70%.

The paper and card content of the MSW stream, sampled at Elstow, in Season 2 is much lower (7.7 and 14.8%) than that presented from the waste flow modelling in Report 1.1 (20.6% used in the models). This is deemed likely due to a high recycling capture rate of these materials, thus lowering the proportion of paper and card in the general MSW stream. However the composition of paper and card observed at Elstow in Season 3 was 22.4%, which is comparable to the composition used in the waste flow modelling.

The paper and card content of mixed C&I wastes [Table 3] varies from 29-42%, and is comparable to the paper and card content (32%) of mixed C&I reported in Report 1.2 (SLR Consulting 2007). The dense plastic content is also similar, with 8% observed in the SLR study whereas at the Shanks sites it was observed to be 10% on average. However the plastic film content observed at the Shanks sites is approximately twice that observed in the SLR study, whereas the plastic film content of the Milton Keynes industrial wastes (sampled separately from commercial wastes) is around the same value, or less than, the proportion observed by SLR. Likewise the commercial waste from Milton Keynes contains a higher proportion of film plastics. The separate commercial and industrial results for the Milton Keynes site are provided in Report 1.2 (Tables 8 and 9) and in Appendix A. Therefore it can be concluded that commercial premises, such as retail and offices, produce greater quantities of film plastics than industrial sectors; due to the increased numbers of refuse sacks used and a greater quantity of packaging waste.

The household and commercial recycled materials [Blochairn 08/12/09 and Broxburn 04/01/10 respectively] both contain large quantities of paper, which is to be expected from a waste collected via local authority recycling rounds. The higher net CV for commercial recycled material is likely to be due to the significantly higher film plastic content, and also as this material has lower moisture content. As is shown in Table 5, the net CV of film plastic is higher than that of dense plastic.

The C&D wastes have consistently contained large quantities of wood waste, more so than any other waste stream, however the bulk component is rubble. The first C&D sample assessed on 18 March 2010 in Season 2 contained a significantly higher proportion of wood than other C&D samples; on this day the batch of C&D consisted of a disproportionate quantity of doors, wooden window frames and beams, showing the inherent variability in composition of waste streams. In all but one of the composition results the inert fraction is a minimum of a third of the total waste mass.

Plastic film, which includes carrier bags and packaging wastes, made up a large proportion of the mixed C&I and MSW materials [9.2-28.5% in season 1 and 15-19.9% in season 2]. These materials are high volume materials; they are lightweight and take up a high proportion volume-wise of the waste materials. These materials are not readily recycled, which explains the high presence of these materials in the waste streams sampled. The future presence of film plastics in residual wastes streams is important when considering the fuel potential of these wastes since film plastics are very high CV materials [39,000 kJ/kg]. The removal of film plastics from the waste stream would subsequently result in a significant decrease in the CV content, and as a result the thermal energy recovery value, of the overall waste.

4.2. Sample analysis

The moisture content of wastes was shown to vary largely, with an average value of 25% across the whole study, however an industrial sample from Milton Keynes contains 71.9% moisture. This is a very high result, though the waste material contained large amounts of wood material [42.9% w/w] which was observed to be very wet when the site was visited. This is likely to be influenced by the adverse weather conditions at the time. This sample also indicated a very low net CV value, which was due to the high moisture content of the waste

As the moisture content impacts on the net CV of the waste materials caution is required when considering these materials as potential fuels. Wastes of higher moisture content would require drying prior to use as a fuel and, in cases where grinding and pre-sorting are required, increase the costs of preparing the material prior to energy recovery. Therefore consideration could be given to waste containers and the collection schemes, including the collection vehicles used, to prevent the addition of rain water to the material before arrival at the treatment facility. Interestingly the average net CV for the C&I wastes is 11,000 kJ/kg- this is similar to an industrially accepted value [~10,000 kJ/kg] used by energy from waste operators, derived from the Biffaward Mass Balance reports.

The ultimate analysis of the wastes indicates that, on a dry basis, the elemental content is consistent for all wastes assessed as part of this project. The standard deviation for carbon, hydrogen and oxygen for all wastes analysed were found to be relatively low, 6.9, 2.2 and 5.8 respectively. However, the standard deviation for the moisture content is significantly greater (stdev = 12.7), and evidently has a large impact on the net CV. As would be expected in the absence of moisture it can be observed that a relatively high gross CV coincides with high carbon content. However, as the net CV was calculated using moisture, hydrogen, oxygen and nitrogen content; consequently high carbon content will not necessarily result in a high net CV.

The highest chlorine content was observed for the C&D waste collected at the Kettering site on 04/05/10. It was observed, on this occasion, that the C&D waste consisted largely of materials resulting from a house being demolished. Therefore the waste contained a large amount of wooden door frames and aggregate material [soil and brick]. However in the waste there was also a quantity of dense plastics which consisted largely of PVC window frames; these result in the chlorine content being 1%, which is roughly 10 times that of all other waste analysed.

	40-200mm Windshifter Kettering 18/1/09	0-40mm Windshifter Kettering 18/11/09	0-6mm Fines Kettering 18/11/09	Textiles MK site 05/2/10	Wood Kettering 05/02/10	Dense Plastics Kettering 05/02/10	Paper/Card Kettering 05/02/10	Film Plastic Elstow 05/02/10	Paper Blochairn 08/2010	Card Blochairn 08/2010
Total Moisture %	22.9	21.4	20.4	3.5	6.2	5.7	5	2.9	5.3	12.2
Ash %	18.6	45.9	68.9	13.3	2.4	1.5	13.2	5.4	3.6	5.6
Volatile Matter %	52.8	37.3	16.7	75	76.1	89.6	72.4	91.6	83.6	75.2
Gross Calorific Value kJ/kg	11,336	9,057	2,181	20,670	18,935	35,180	15,602	41,321	15,446	15,889
Net Calorific Value kJ/kg	9,969	7,812	1,316	19,297	17,614	33,110	14,403	39,057	14,362	14,775
Carbon %	49.90	73.30	48.19	58.41	51.26	76.69	48.09	85.08	49.90	73.30
Hydrogen %	6.12	8.10	5.57	6.62	5.90	11.03	5.93	14.32	6.12	8.10
Nitrogen %	0.67	2.60	2.41	4.21	0.63	0.26	0.43	0.43	0.67	2.60
Oxygen %	42.29	12.22	30.64	30.26	42.13	11.85	45.46	0.11	42.29	12.22
Sulphur %	0.70	3.76	12.44	0.44	0.04	0.08	0.07	0.02	0.70	3.76
Chlorine %	0.32	0.03	0.74	0.06	0.03	0.10	0.02	0.03	0.32	0.03

Table 5. Detailed analysis of individual components and separated materials. Elemental analysis adjusted to moisture free.

Paper and card yield the lowest net CV [14,400 kJ/kg] of the analysed waste components. These were also present in relatively high proportions in the C&I fractions shown in Table 3. As paper and card are commonly recycled (especially for MSW streams) consideration should be given to the benefits of recycling this material and the potential impacts on the fuel value of the overall waste stream.

The film and dense plastic materials indicate a significantly higher net CV [39,000 and 33,000 kJ/kg respectively] than the other components. Film plastic, however, is not commonly source-segregated for recycling collections. The chlorine and sulphur content of these plastic streams are not higher than other materials, and so further consideration should be given to the environmental emissions resulting from the use of these materials as a fuel.

Consideration needs to be given to the renewable content of the recyclable materials which have potential application in energy recovery processes. Paper and card materials are mostly renewable resources yet contain much lower energy content than plastics, however plastics are generally produced from petroleum products, and so are inherently non-renewable resources. Further consideration would be required, including a detailed analysis of CO_2 emissions, taking into account the separation, transportation and processing of the wastes to determine the most suitable route of recyclable materials (recycling or energy recovery).

4.3. C&I plastic content

The plastics arising in the C&I waste materials assessed during Season 3 is presented in Figure 3.

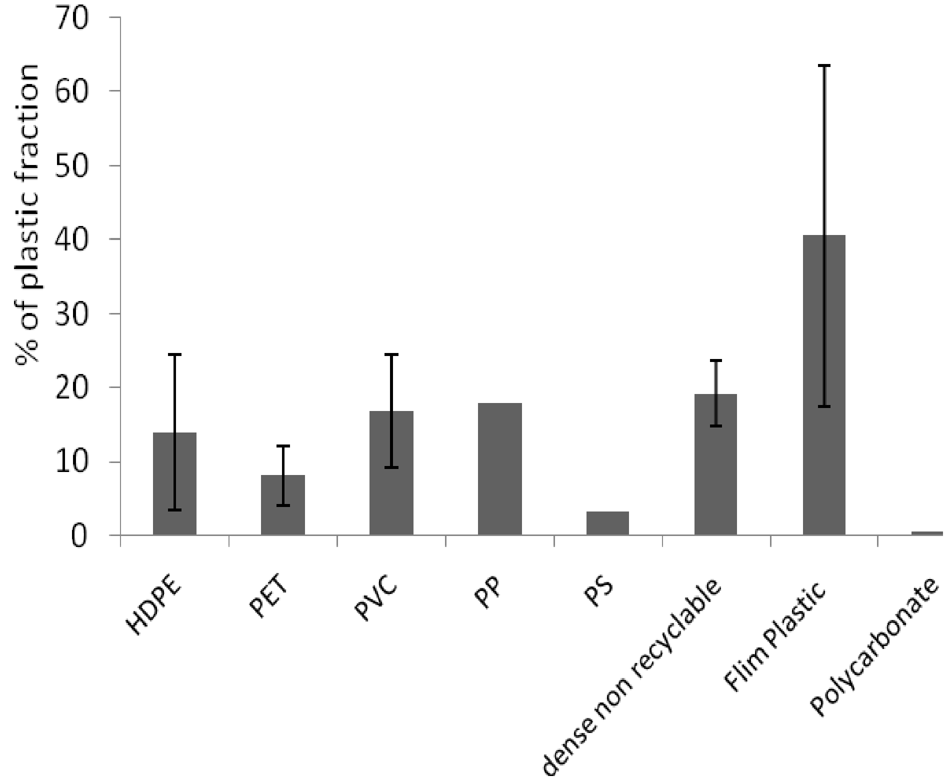

Figure 3. Proportion of each plastic type observed in C&I wastes. Error bars shown as standard deviation.

On average, the dense non recyclable plastics represent the highest fraction. It is composed of mixed dense plastic which was either not identifiable as a certain plastic type or composed of various, not easily separable plastic types. This fraction accounted for about 20% in three cases and for 50% in one case. The second highest plastic type is HDPE [14%], followed by PET [8%]. Both HDPE and PET mainly consist of plastic bottles and a small amount of other food packaging. PVC represents the next highest plastic type proportion with 7.7%. However, this number derives basically only from one site visit, where PVC material in the form of window frames and pipes was found. Clearly identifiable PVC like pipes, window frames, flooring, wire coating or floor coverings could not be found in the other site visits. The fourth highest plastic type is represented by PP with 4% and followed lastly by PS and Polycarbonate, both account for less than 1% and identified in each case only once.

The proximate and ultimate analyses of the plastic types are shown in Table 6.

	Film	HDPE	PET	PS	Non	PP
Proximate Analysis						
Total Moisture	0.2	0.3	2.1	2.2	0.2	0.4
Ash	0.3	0.9	2.5	1.4	0.7	1
Volatile Matter	89.7	87.4	85.2	87.5	87.3	86.5
Fixed Carbon	9.8	11.4	10.2	8.9	11.8	12.1
Adjusted Ultimate Analysis (%)						
Carbon*	72.4	73.7	70.1	69.9 (90)	75.6	74.1
Hydrogen*	4.6	4.5	4.3 (4.2)	4.0 (10)	4.8	4.0
Nitrogen*	0.6	0.3 (0)	0.4 (0)	0.4 (0)	0.3	0.5
Oxygen*	22.3	21.4 (0)	25.0	25.5 (0)	19.1	21.3
Sulphur*	0.1	0.1 (0)	0.1 (0)	0.1 (0)	0.1	0.1
Chlorine*	0.1	0.1 (0)	0.1 (0)	0.1 (0)	0.1	0.1
Gross cal.val. kJ/kg	29,000	29,400	30,000	28,800	30,000	29,200
Net cal.val. kJ/kg	27,600	27,400	28,000	26,800	27,900	27,200

Table 6. Proximate and ultimate analysis of the plastic types assessed specifically in Season 3. ***(Theoretical value)**

Overall it can be observed that the plastic types show a relatively low moisture and ash content if compared to other typical fuel materials like biomass (treated wood) or coal (bituminous, coal) (Phyllis, 2009b). Also the percentage of fixed carbon was comparatively low while the volatile matter content was high. The content of hydrocarbons is very high in each of the plastic types, carbon accounting for about 73% and hydrogen accounting for about 6%. The S and Cl content are low for all analysed plastic types. The results of the plastic fraction of C&I waste part of a Masters level research project investigating the economics of recycling plastic materials vs. the energy recovery potential. This project was undertaken at Cranfield University and a poster presented at the end of the MSc thesis project is included as Appendix C. Further work is recommended to assess the environment impacts of handling plastic wastes, and consideration needs to be applied to the compliance of plastic wastes to the emissions limits imposed by the EU Waste Incineration Directive (Council of the European Union 2000).

4.4. Site waste arisings

The quantity of specific waste materials arriving at each of the sampled Shanks waste sites is shown in Figure 6. Milton Keynes is not shown due to the site only operating for 3 months during 2009.

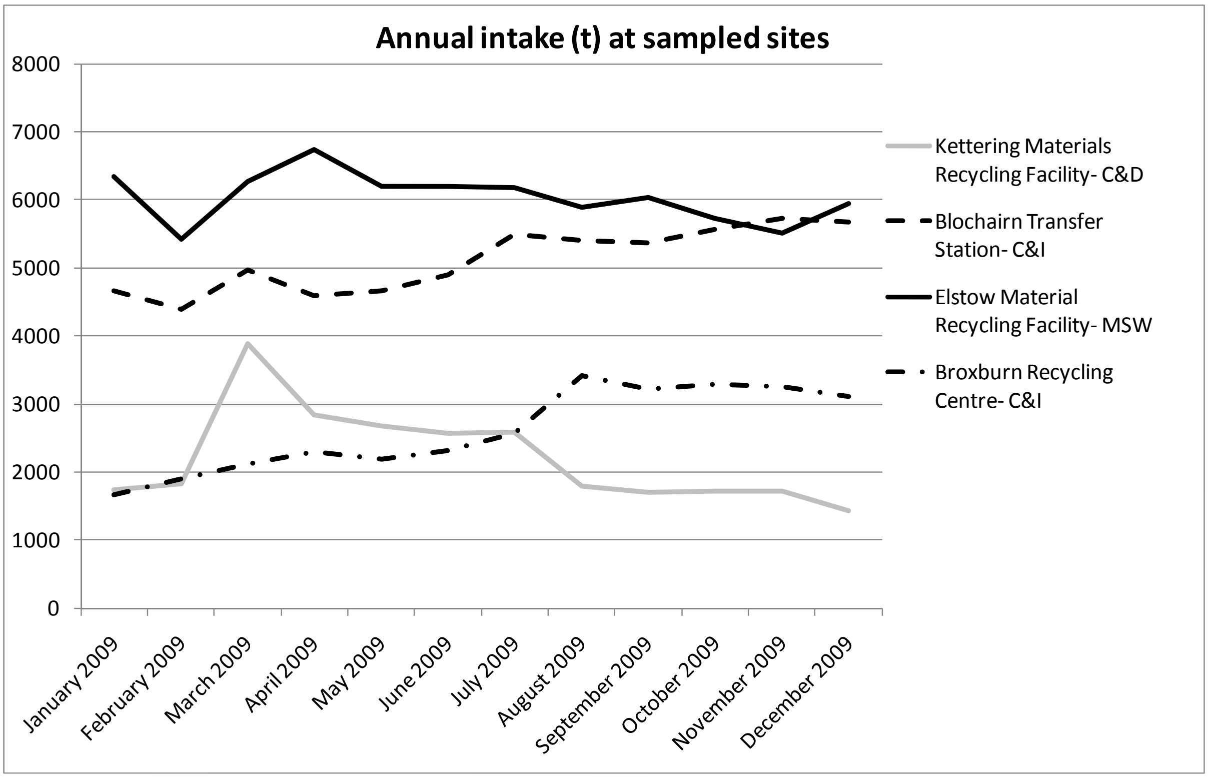

Figure 6. Quantity of specific waste materials arriving at sampled Shanks sites.

Waste arisings are variable, as is the composition, and this is shown in Figure 6. A number of factors can explain the fluctuations and growth in waste arriving at the sites, such as adverse weather [flooding and snow], site building work, changes in contracted collections, economic impacts etc. For example, over the winter period there was a relatively low quantity of C&D waste arriving at the Kettering site, this could be due to the snowfall in the area causing a backlog of materials at the construction sites, resulting in a very sudden increase in March.

The fluctuations in quantities and composition of waste arriving are a result of seasonal and economical changes. These variations pose a risk, which should be considered in the design of energy from waste facilities. The risk of composition changes can be addressed through pre-processing of waste and bulking of the refined fuel. For example, if a waste contains between 5-10% metal then efficient removal of this through a material recycling factory [MRF] would refine the waste material as a fuel. The level of pre-processing required for the use of waste materials as a fuel is dependent on the energy recovery technology and the associated tolerances; a higher level of pre-processing required results in a high cost, and possibly a higher quantity of waste material [i.e. inert from C&D wastes]. Therefore variability in the waste composition can be offset by adaptable processing of the waste to yield consistent fuels.

The quantities of waste arriving at each of the Shanks wastes sites and an overview of the average calorific content of these materials is summarised in Table 7. The Milton Keynes annual tonnage was not available due to the short period of overall operation time.

Site [waste type]	Total annual waste [t]	Non-inert material Average Net CV [kJ/kg]	Total material Average Net CV [kJ/kg]
Aylesbury [C&I]	33,700	17,875	15,498
Blochairn [C&I]	61,400	14,099	10,867
Broxburn [C&I]	31,300	15,010	11,892
Elstow [MSW]	72,500	11,740	9,222
Kettering [C&D]	26,500	11,842	3,590
Milton Keynes [C&I]	n/a	10,600	8,814

Table 7. Total annual energy potential for each material sampled at each site.

The net CV for C&D wastes throughout was low, which is expected due to the very high content [65.1, 39.2, 66.1 and 74.1%] of inert materials [aggregate]. Whilst the net CV content of the non-inert material is comparable to other waste streams the inert fraction [aggregate, glass and metals] accounts for up to 74% of the waste material. Therefore a significant amount of material would need to be removed from the waste prior to use as a fuel, resulting in subsequent disposal/handling costs of the inert materials.

4.5. Image analysis

Images from C&I waste, from the first season, were analysed with the dot-grid method.

The adjusted model, which took the varying densities of waste materials into account, provided significant improvements in terms of correlation and differences between the IA and HS values. The correlation coefficient resulted r=0.921 and R^2=0.8489 between the value of the IA adjusted and HS method (Figure 5). IA adjusted is the proportion of each waste component determined by the number of dots corrected for the relative density of each component. For example, wood weighs more than film plastic; therefore if each component was covered by 50% of the dots then this is adjusted to allow for the differences in mass that this corresponds to yield a % w/w for each component. Further detail is provided in Appendix B.

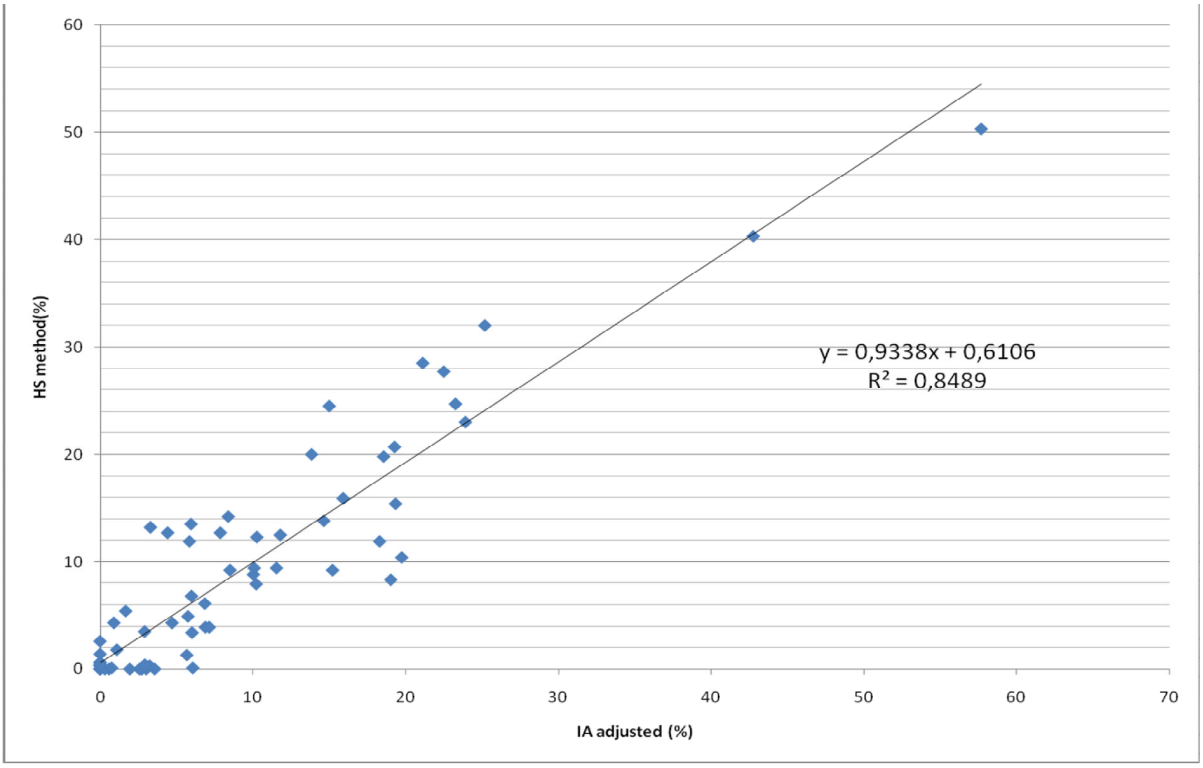

Figure 5. Correlation $IA_{adjusted}$-HS

Time reduction was obtained by reducing the number of images in the batch analysed, and then the result analysed to highlight the effect on the accuracy. Six batches of images were taken randomly from the 30 gathered during the site visits. Groups of 25, 20, 15, 10, and 5 images were analysed and compared with the relative group result obtained with IA method. Five trials of 5x batches of images have been tested to see the degree of similarity. This procedure was repeated for each of the six days (C&I surveys in Season 1) and correlations related to the whole dataset formed by the 6x day data per trial.

Correlations for each group were found to be very close to the initial 30x Images used for the analysis, initially shown in Figure 5. However paired differences in standard deviations and standard error mean increase with a reduction in the batch size.

The average correlation coefficients found were: 25 images r=0.999; 20 images r=0.998; 15 images r=0.995; 10 images r=0.991 and 5 images r=0.979. Nevertheless, considering the value of differences in standard deviations it is not recommended to use less than 15 images, as individual images are not representative of the whole waste sample, so a low number of analysed images could lead to big errors in categories estimation.

This method has indicated that there is the potential for applications in waste composition studies, such as those carried out in this work package. Further development is required for this, and where possible research is recommended to automate the image analysis process within feasible technological and economical constraints.

5. Conclusions

5.1. Development outcomes

The image analysis technique was developed based on the findings of previous research undertaken at Cranfield University. This technique has been shown to correlate strongly with the traditional hand sorting method. As the image analysis technique assesses a much greater quantity of waste materials a more in-depth understanding of the variation and representativeness of the total waste sample is enabled. It therefore provides an innovative method of gaining a much larger sample set without having to physically sort through the waste material, which is time consuming and disruptive to site operations.

A major driver behind the use of certain materials as a fuel is the commodity value. This is the financial benefit of separating a specific waste component for reuse. Certain components, such as specific plastics, provide a financial incentive to the waste treatment operator. However if the market value of the recyclate was to drop or the energy value was to increase due to technological advance, then the ongoing separation of that recycled material may no longer be profitable and as a result would remain in the mixed waste stream, available as a fuel.

Research undertaken at Cranfield University has assessed the composition of each type of plastic [e.g. high density polypropylene, HDPE] in C&I mixed wastes, and compared the energy value with the commodity value. This is provided in Appendix C, and demonstrates that if plastics were to be used in a combined heat and power [CHP] facility then the plastics are economically favourable as a fuel. However in a straight forward incineration facility it is economically favourable to recycle the plastics. The differences were found to be minimal, however, and as such this balance could shift in scenarios where the energy prices increase; the commodity value of plastics decreases; the plastics are used in a more power-efficient energy recovery system, such as CHP or possibly advanced thermal processes. These conclusions are based entirely on economic factors, and do not take into account the use of plastics for energy recovery as part of the waste hierarchy or the effects on CO_2release. Further research is recommended on the environmental impacts of recycling plastics or use in energy recovery; this could take the form of a lifecycle analysis and compare the differences between CO_2 emissions.

5.2. Project overview: lessons learned and key findings

This work package aimed to collate UK waste data from a number of sources, identify knowledge limitations and produce new data which enhances understanding of UK wastes. The improved understanding of the wastes will subsequently allow the overall ETI project objectives to be met, which are to identify the next generation of technologies which can be used to generate energy from a wide variety of available waste materials.

Based on the findings of this work, including previous reports, several key points can be raised regarding the understanding of UK waste arisings.

Understanding of recycling trends, such as increased recycling rates in C&I waste streams and the shift of recycling rates in MSW. It is concluded that commercial premises, such as retail and offices, produce greater quantities of film plastics than industrial sectors; due to the increased numbers of refuse sacks used and a greater quantity of packaging waste. There is a notably higher proportion of recyclable material present in mixed C&I wastes, and as such there could be a decrease in these materials in the future;

- Driven by economic factors, government and local authority level targets;
- Using the known factors to estimate future recycling trends;
- Estimate the effects of changes in recycling levels on the composition of residual wastes, moisture content and net calorific value;

Therefore, the true value of a waste material as a resource needs to be considered. Essentially the drivers are economic in that if a recyclable material is more or less valuable as a commodity than as a fuel material. It should also be noted that many recyclable materials, such as plastics and paper, cannot be continuously recycled due to the degradation and/or contamination of the materials as they are reprocessed. As a result, there will always be 'recyclable' materials within the residual stream. Recycling cannot be the complete solution, but will remain for as long as it is practically and economically viable to do so.

A rapid assessment tool has been developed as part of this project in the form of an image analysis method. This has shown potential as an alternative method of monitoring waste composition. Additionally analytical methods developed at Cranfield University could be utilised in understanding the biogenic carbon content of heterogeneous waste materials, which is useful for the allocation of renewable obligation certificates [ROCs]. An overview of this project is shown in Appendix D.

The understanding of the content, energy value and elemental composition of residual C&I wastes has been developed and enhanced. However a more detailed understanding of the wastes arising from specific industrial sectors would allow a greater insight into the impacts of specific commercial activities on the energy value of C&I wastes. The current C&I survey being undertaken by Defra would be highly complementary to the data obtained within this project. However as the results of the Defra survey will not be published until early 2011 this is not possible at this time.

Equally, it would be valuable if all wastes arriving at the transfer stations could be allocated, proportionately, to specific SIC codes. This would allow a greatly improved understanding of the mixed residual wastes collected. This has not been practically possible to date. An alternative to this would be a large scale waste composition study which collects waste samples from pre-specified locations, such as retail, catering, education etc;

- Could be linked to economical changes for each sector;
- And waste minimisation strategies specific to different sectors.

A number of key findings have been outlined in this report, however a number of areas require further work which could be addressed in future projects which could provide the resources and timescales necessary.

C&I wastes have yielded the highest net CV (allowing for moisture content), and based on the existing understanding of C&I arisings it can be concluded that C&I wastes have the highest potential for use as an energy material. The C&D waste stream contains such a large quantity of inert aggregate material that the net CV is much lower than that of C&I and MSW materials.

The potentially recyclable materials present in the residual wastes, in particular C&I, is of importance. The plastic materials contribute significantly to the CV of the overall material, and knowledge of future recycling trends would be important.

In summary, this report is the final deliverable for work package 1 of the ETI-funded project. This report represents data and findings obtained over a period of one year, and provides key insights into the properties, quantities and drivers of waste materials suitable for energy recovery. Further research is required in a number of areas in order to maximise the understanding of the factors which need to be taken into account when planning energy from waste facilities.

6. References

Council of the European Union (2000). "Directive 2000/76/EC on the Incineration of Waste." Official Journal of the European Communities **L 332**: 91-111.

Defra. (2010). Survey of commercial and industrial waste arisings 2010- final results. London, UK.

SLR Consulting (2007). Determination of the Biodegradability of Mixed Industrial and Commercial Waste Landfilled in Wales.

A. Waste data for each season

		Season 1								
	Site-	Blochairn	Blochairn	Broxburn	Broxburn	Kettering	Milton Keynes	Milton Keynes	Milton Keynes	Milton Keynes
	Sample type-	Co-mingled hh recycling	Mixed C&I	Mixed commercial recycling	Mixed C&I	C&D	Mixed commercial	Mixed commercial	Mixed industrial	Mixed industrial
	Date-	08/12/2009	09/12/2009	04/01/2010	05/01/2010	25/11/2009	23/11/2009	24/11/2009	23/11/2009	24/11/2009
Physical Composition (% weight)	Paper	50.3	24.7	40.3	24.5	3.9	13.8	23.0	4.4	8.8
	Card	20.0	10.4	27.7	15.9	2.8	15.4	19.8	7.4	20.8
	Wood	0.0	0.0	0.0	0.0	17.7	13.2	6.8	42.9	33.5
	Metals	3.4	13.5	1.3	6.1	4.1	0.1	11.9	9.7	4.2
	Glass	3.5	0.3	0.0	4.3	0.0	12.7	0.4	0.3	0.1
	WEEE	0.0	0.3	0.0	0.0	1.7	0.1	1.8	1.8	0.1
	Textiles	4.3	0.0	0.0	8.8	0.3	0.1	5.4	1.1	1.3
	Dense Plastics	12.3	9.2	12.7	7.9	1.8	3.9	9.4	26.5	5.8
	Plastic Film	1.4	28.5	14.2	9.2	2.5	8.3	9.4	2.8	4.0
	Organic Fines	4.9	12.5	3.9	20.7	0.0	32.0	11.9	2.9	8.5
	Inert/Agg/Soils	0.0	0.6	0.0	2.6	65.1	0.6	0.4	0.2	12.6
	Misc. Comb									
Proximate	Total Moisture %	38.7	9.1	24.6	27.7	26.7	31.3	47.8	52.7	71.9
	Ash %	15.2	21.7	14.6	9.4	5	9.5	13	16	11
	Volatile Matter %	42.6	65	58.6	54.5	58.7	52.7	37.8	25.9	14.5
	Gross CV kJ/kg	8,504	13,079	11,295	10,456	3,798	10,432	6,417	6,582	2,870
	Net CV kJ/kg	5,549	10,516	7,119	7,452	3,030	7,462	3,817	4,616	912
Ultimate elemental analysis (%)	Carbon %	50.99	53.60	50.54	49.26	46.86	51.14	51.20	60.64	44.45
	Hydrogen %	5.93	7.14	6.22	6.23	5.83	6.16	6.17	7.97	4.88
	Nitrogen %	0.45	0.76	0.33	0.43	0.31	0.35	0.36	0.83	5.11
	Oxygen %	42.45	38.07	42.76	43.83	46.78	42.19	42.07	29.96	44.74
	Sulphur %	0.09	0.26	0.08	0.10	0.09	0.08	0.05	0.32	0.35
	Chlorine %	0.09	0.17	0.07	0.16	0.13	0.07	0.15	0.29	0.46

		Season 2							
	Site-	Blochairn	Elstow	Elstow	Kettering	Kettering	Milton Keynes	Milton Keynes	Milton Keynes
	Sample type-	C&I	MSW (general)	MSW (general)	C&D	C&D	Mixed commercial	Mixed industrial	Mixed industrial
	Date-	01/04/2010	25/02/2010	17/03/2010	18/03/2010	04/05/2010	04/05/2010	04/05/2010	05/05/2010
Physical Composition (% weight)	Paper	17.5	4.7	12.7	0.1	0.0	19.5	3.9	2.9
	Card	15.8	3.0	2.1	5.3	0.0	11.4	6.3	37.9
	Wood	0.9	2.7	0.3	39.4	14.3	0.0	45.5	31.8
	Metals	4.7	6.4	1.2	2.1	2.0	1.4	0.8	5.0
	Glass	0.0	5.7	4.4	0.1	4.0	4.8	0.0	0.0
	WEEE	0.4	5.1	0.0	0.0	0.0	0.0	0.0	0.0
	Textiles	9.0	7.1	11.5	4.1	0.0	5.2	18.5	2.0
	Dense Plastics	9.0	14.5	3.6	5.5	11.6	11.0	10.4	2.3
	Plastic Film	15.0	19.9	18.0	4.2	0.0	15.7	3.7	9.6
	Organic Fines	21.4	22.2	37.0	0.0	0.0	31.0	0.6	8.5
	Inert/Agg/Soils	0.0	0.0	0.0	39.2	66.1	0.0	5.7	0.0
	Misc. Comb	6.4	8.8	9.2	0.0	2.0	0.0	4.7	0.0
Proximate	Total Moisture %	23.6	53.4	40.9	11.5	17.4	23.7	12.1	11.0
	Ash %	13.4	9.3	12.5	53.2	37.2	10.0	4.6	8.2
	Volatile Matter %	56	33.1	40	35.2	44.9	36.4	75.6	73.6
	Gross CV kJ/kg	11,849	6,205	10,167	4,592	2,497	13,750	13,817	14,271
	Net CV kJ/kg	8,707	4,541	8,443	3,859	2,320	11,221	11,906	7,977
Ultimate elemental analysis (%)	Carbon %	50.70	49.51	49.50	39.15	17.20	35.20	41.10	42.46
	Hydrogen %	6.56	6.10	6.13	4.05	0.40	3.20	4.00	4.30
	Nitrogen %	0.55	0.75	2.09	1.88	2.50	1.50	1.10	1.30
	Oxygen %	41.81	43.33	41.32	52.28	78.40	59.50	53.50	51.75
	Sulphur %	0.13	0.19	0.28	1.91	0.50	0.30	0.10	0.10
	Chlorine %	0.25	0.13	0.68	0.73	1.00	0.30	0.20	0.10

		Season 3						
	Site-	Aylesbury	MK	MK	Blochairn	Broxburn	Elstow	Kettering
	Sample type-	C&I	C&I	C&I	C&I	C&I	MSW	C&D
	Date-	27/05/2010	02/06/2010	29/06/2010	03/06/2010	03/06/2010	10/07/2010	15/06/2010
Physical Composition (% weight)	Paper	12.0	19.9	50.9	20.0	14.7	8.4	0.0
	Card	9.9	16.7	7.0	13.1	13.4	14.0	0.0
	Wood	5.9	3.5	1.0	15.8	7.8	7.0	13.8
	Metals	1.4	2.3	7.0	0.5	2.2	7.0	0.5
	Glass	2.0	0.3	4.0	1.4	0.8	3.5	0.0
	WEEE	0.0	0.0	1.5	0.0	0.0	0.0	0.0
	Textiles	20.1	7.1	4.0	1.3	4.5	3.5	3.3
	Dense Plastics	20.7	6.4	11.0	6.7	11.5	7.0	3.1
	Plastic Film	17.3	12.9	10.0	15.5	15.1	7.0	1.5
	Organic Fines	10.7	27.7	1.7	15.6	30.1	28.0	0.3
	Inert/Agg/Soils	0.0	0.0	0.0	7.4	0.0	3.5	74.1
	Misc. Comb	0.0	3.2	2.0	2.6	0.0	11.2	3.3
Proximate	Total Moisture %	7.2	9.6	43.0	11.2	11.6	28.0	22.5
	Ash %	6.0	4.4	7.1	7.6	11.5	11.3	14.5
	Volatile Matter %	79.8	80.0	45.1	74.9	71.5	48.2	58.4
	Gross CV kJ/kg	18,577	15,188	15,269	16,834	20,379	18,858	5,541
	Net CV kJ/kg	15,498	11,686	13,059	13,380	16,332	14,681	5,152
Ultimate elemental analysis (%)	Carbon %	55.24	43.69	62.07	51.32	58.23	66.00	55.99
	Hydrogen %	3.00	2.83	2.73	2.80	2.64	4.06	2.79
	Nitrogen %	0.80	0.57	0.37	0.79	0.60	0.43	0.55
	Oxygen %	40.76	52.71	34.53	44.90	38.32	29.31	40.47
	Sulphur %	0.10	0.10	0.20	0.09	0.10	0.10	0.10
	Chlorine %	0.10	0.10	0.10	0.09	0.10	0.10	0.10

		Season 4					
	Site-	Aylesbury	Aylesbury	MK	Blochairn	Broxburn	Kettering
	Sample type-	C&I	C&I	C&I	C&I	C&I	C&D
	Date-	09/09/2010	15/09/2010	08/09/2010	16/09/2010	16/09/2010	15/09/2010
Physical Composition (% weight)	Paper	16.7	34.6	14.4	40.4	31.0	0.0
	Card	31.6	13.5	7.2	20.2	2.6	0.3
	Wood	7.4	7.7	7.8	0.9	0.0	17.4
	Metals	2.2	2.9	3.3	2.6	0.6	0.0
	Glass	1.8	0.0	2.6	0.0	0.0	0.0
	WEEE	0.0	0.0	4.6	0.0	0.0	0.0
	Textiles	7.2	0.0	1.3	0.0	1.9	0.9
	Dense Plastics	16.1	14.4	10.5	15.8	6.5	3.0
	Plastic Film	7.2	9.6	35.9	14.0	38.1	0.4
	Organic Fines	1.6	12.5	11.8	4.4	12.9	0.0
	Inert/Agg/Soils	6.0	2.9	0.0	0.0	0.0	78.0
	Misc. Comb	2.4	1.9	0.7	1.8	6.5	0.0
Proximate	Total Moisture %	11.0	10.9	7.9	8.0	12.5	20.6
	Ash %	31.9	11.3	16.2	14.2	6.3	29.6
	Volatile Matter %	52.7	72.0	70.7	73.3	76.7	45.9
	Gross CV kJ/kg	14,175	19,856	18,780	19,978	19,924	2,752
	Net CV kJ/kg	8,556	15,825	16,063	14,728	18,048	2,520
Ultimate elemental analysis (%)	Carbon %	52.83	56.30	60.30	56.15	57.80	56.40
	Hydrogen %	0.20	0.47	0.47	0.50	0.40	0.25
	Nitrogen %	0.10	0.17	0.23	0.15	0.30	0.20
	Oxygen %	46.80	42.60	38.57	42.40	40.80	42.85
	Sulphur %	0.10	0.13	0.17	0.20	0.20	0.15
	Chlorine %	0.13	0.40	0.40	0.60	0.50	0.20

B. Image analysis method

The images were imported into Erdas Imagine v9.1 and geometrically corrected in order to obtain a squared image of a defined 1 m^2 area.

The corrected image was then analysed, using RGB or/and IHS variations when objects were no longer recognisable in the image.

The image was loaded and the dot-grid overlapped. Information from the pre-processing stage (notes and initial observations), were now useful to better identify the objects.

Larger objects were identified and the dots within their borders, clustered with the perimeter drawing tool. In order to facilitate the recognisability of dots during the counting phase, a label list was previously created in which each colour was linked to a specific category of waste. Each object selected was then automatically coloured with the related category colour [Figure 2].

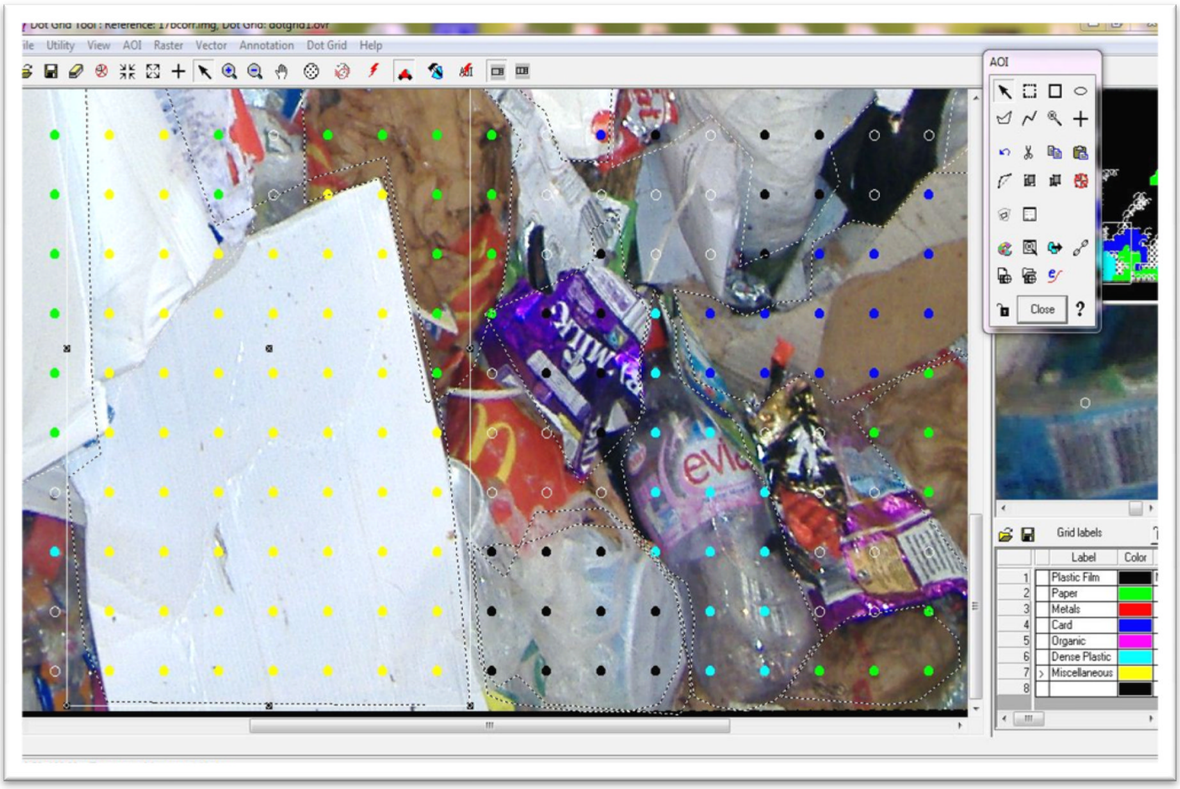

Figure b1. Example of Dot Analysis

Once the biggest pieces were processed, the image was zoomed and each dot manually coloured. Finally the dots were counted and the categories quantified in terms of dots. This procedure was repeated for each image. The area of the category (i) in the image (n) was calculated with the following formula:

$$\text{Area Category(i) Image (n)} = \frac{Number\ of\ dots\ of\ the\ category(i)}{Total\ number\ of\ dots\ in\ the\ grid} \times 1m^2$$

Where (i) is one of the 11 categories, (n) one of the 30 images of the selected set, the total number of the dots represents the resolution of the grid and $1m^2$ is the area of the image. Therefore, this result was expressed in m^2. The % of category on 30 images was then calculated as the mean value out of the 30 images.

The outcome from this step was the area occupied by each category for each batch of 30x images/site.

Finally each dataset was inserted in a spreadsheet where IA output was used with the relative densities data and compared with HS datasets.

The data was then adjusted based on density of each component:

$$Adjusted\ IA\ Composition\ of\ Waste\ (\%) =$$

$$\left[\frac{\%\ \text{paper - }(a_1)}{\text{b}}\times 100\right];\ \left[\frac{\%\ \text{cardboard - }(a_2)}{\text{b}}\times 100\right];\ \dots;\ \left[\frac{\%\ \text{inert - }(a_{11})}{\text{b}}\times 100\right].$$

Where:

a_n is the adjustment factor specific for each category

b is the total weight of the sample

Cranfield UNIVERSITY

C. MSc thesis project poster- Mixed Plastics in Commercial and Industrial Waste: Recycling vs. Energy Recovery

Mixed Plastics in Commercial and Industrial Waste: Recycling vs. Energy Recovery

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Supervisors: Dr Stuart Wagland
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Cranfield UNIVERSITY
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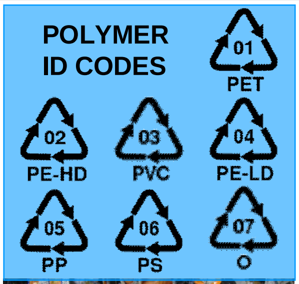
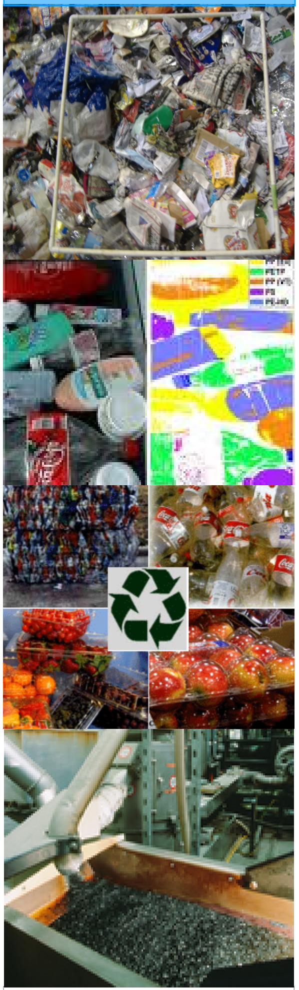
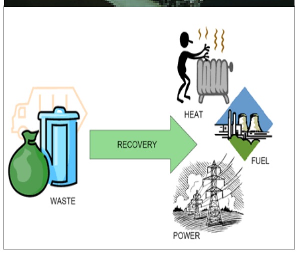
Sustainable Systems Department
SCHOOL OF APPLIED SCIENCES





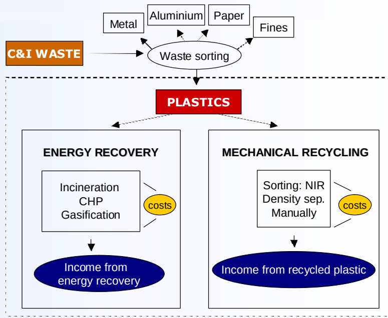


Objectives

- ❑ Determine the individual plastic types in C&I waste
- ❑ Identify whether recycling or energy recovery of plastic types from C&I waste is economically favorable
- ❑ Within the economic analysis, consider environmental issues and operational steps

Methodology

Moisture
Volatile matter
Ash
C
H
N
O
S
Cl



SITE WORK

- Identify plastic arisings by proportion of total C&I waste
- Investigate composition of plastic types

LAB ANALYSIS

of single plastic types:

- Ultimate analysis
- Proximate analysis
- Calorific Value

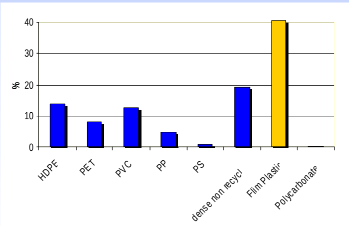
ECONOMIC ANALYSIS

Costs of separation and fuel preparation are offset against the value of recovered plastic and income from energy generation respectively

Results

UK annual amount of C&I waste: 83 million tonnes
Plastic arisings from C&I waste: 3.3 million tonnes (*Source: Defra, 2007*)

PLASTIC COMPOSITION



- 60% dense and 40% film plastic
- plastic packaging: 25%
- non recyclable, dense plastic 20%

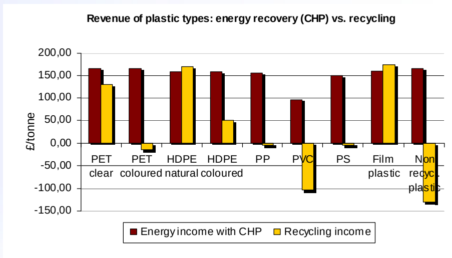
CHEMICAL RESULTS

	Film plastic	HDPE	PET
Total Moisture	0.2	0.3	2.1
Ash	0.3	0.9	2.5
Volatile Matter	89.7	87.4	85.2
Carbon	72.5	73.8	93.8
Hydrogen	4.6	4.5	4.6
Nitrogen	0.6	0.3	0.2
Oxygen	22.3	21.4	1.4
Sulphur	<0.1	<0.1	<0.1
Chlorine	<0.1	<0.1	<0.1
Gross cal.val. kJ/kg	29,000	29,400	30,100
Net cal.val. kJ/kg	27,600	27,400	28,000

Biggest outlier: Chlorine of PVC: 47.7% *(Source: Sorum, 2001)*

- low moisture content
- relatively low ash content
- PVC: very high Cl content
- high cv (comparable with coke)

ECONOMIC ANALYSIS



- CHP is generally more economically favourable due to high plant-efficiency
- considering 1 tonne of the investigated plastic composition, £ 83 can be earned when recycled, £ 135 can be earned when incinerated
- if only electricity is produced, recycling is economically favorable
- high recycling potential for film plastic, HDPE and PET clear

Conclusion

- ❑ **Energy recovery in a CHP plant for most plastic types the economically favorable option**
- ❑ Recycling performs better (economically) for film plastic and HDPE natural
- ❑ If energy recovery (electricity only): recycling most favorable
- ❑ Environmental limitations most significant with PVC (HCl)

Sponsored by: energy technologies institute; shanks. waste solutions.

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D. MSc thesis project poster- Development of an Image-based Method for Determining Waste Composition

Development of an Image-based Method for Determining Waste Composition

Student: Francesco Veltre

Supervisors: Dr. Phil Longhurst
Dr. Stuart Wagland

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Centre of Resource Management and Efficiency
Sustainable Systems Department
School of Applied Science

Aims

- ❖Development of a methodology to determine waste composition from image analysis
- ❖Comparison with hand sorting data from Commercial and Industrial waste materials
- ❖Identification of development requirements

Study

Fieldwork

- ➢Hand Sort (HS) of sample
- ➢Collection of images

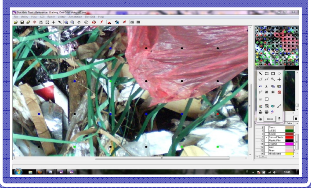
- ➢Generation of density data

Data/Site

- ➢1x HS (=5-10% waste layer)
- ➢30x images (= 30m² →100% waste layer)
- ➢Density dataset

Computer-based work

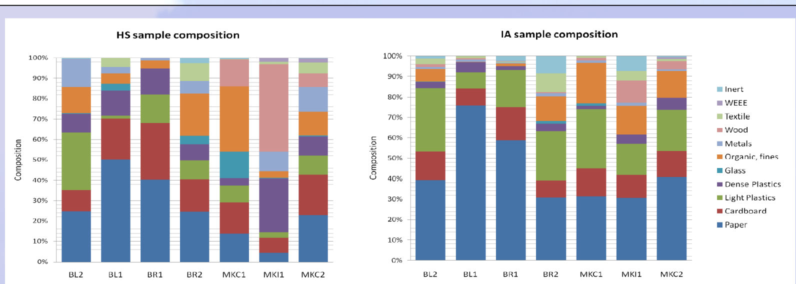
- ➢Image correction
- ➢Analysis of images



- ➢1x SET OF PROCESSED IMAGES

COMPARISON

Results



INITIAL FINDINGS

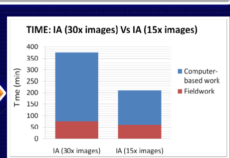
- ➢ IA was used with relative density data and compared with HS;
- ➢It was observed that percentage of categories resulted in some components being under/over-estimated;
- ➢Time required for IA was still significantly higher than HS;
- ➢Therefore, adjustments were applied.

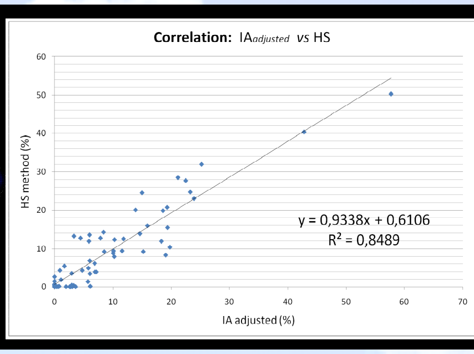
Improvements

$$\textit{Adjusted IA Composition of Waste}\ (\%) = \left[\frac{\%\ \text{paper} - (a_1)}{\text{b}} \times 100\right];\ \left[\frac{\%\ \text{cardboard} - (a_2)}{\text{a}} \times 100\right];\ \ldots;\ \left[\frac{\%\ \text{inert} - (a_{11})}{\text{b}} \times 100\right]$$

Where:
a_n is the adjustment factor specific for each category;
b is the total weight of the sample adjusted, expressed as: b= (% paper - a_1) + (% cardboard – a_2) + . . . + (% inert – a_{11})
with (% category – (a_i)) ≥ 0. If (% category – (a_i)) < 0 then it is imposed =0 and b update.

The best option in terms of accuracy vs time - a reduced batch of 15 images instead of 30





Conclusions

- ➢The IA method has potential in characterising waste composition under specific assumptions
- ➢Despite limitations, IA method and HS correlate significantly
- ➢Adjustments enhance the method in terms of time and accuracy
- ➢Further work is required to improve the method

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energy technologies institute
shanks. waste solutions.