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# Engineering value recovery from municipal solid waste

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**Abstract:** As world population and industrialization increase, the consequence has been an increase in waste generation. In an attempt to curb this increase and recover value from the waste streams, the European Union (EU) and UK have introduced a wide range of legislation, focusing to a large extent on the biodegradable component of municipal solid waste (MSW). Although by no means the largest component of the total waste generated, it is a significant contributor to greenhouse gas emissions if left unmanaged. Strict targets for its diversion from landfill have been set and these will become increasingly challenging between 2010 and 2020. Despite the raft of legislation, this article demonstrates that the definitions and properties of MSW and its management strategies can vary considerably across the EU. Variations also exist across the UK, making it difficult to compare one region and its management strategies to another. The generic role of the materials recovery facility (MRF) is seen as crucial by the authors and this article examines its place across the management spectrum. Data are presented to demonstrate the effectiveness of one such MRF operating in both 'clean' and 'dirty' modes. Its ability to recover product streams such as ferrous metal, aluminium, plastic containers, paper, and card is reported along with a brief economic assessment.

**Keywords:** materials recovery facility, municipal solid waste, waste composition, recovery, design

## 1 INTRODUCTION

Consider the current world scenario: global warming is an accepted fact of life. The North Pole has lost a third of its ice cap and the world has seen some exceptional adverse weather conditions. The economies of China and similar countries are growing at a phenomenal rate and are now sucking in a disproportionate fraction of the world's natural resources. Furthermore, the recent global recession has slowed down world output, and every sector of commerce and industry, including recycling, has faced serious pressures in terms of stable markets and prices.

It is also the unfortunate fact that while technological progress over the past three centuries has facilitated much of the population growth, chiefly with measures such as improvements in sanitation, medicine, and intensive farming, its by-product has been the considerable rise in all forms of waste and pollution. To sustain this growth, material consumption has also grown to reflect both the impact of population and that of increased worldwide industrial globalization; again with growth comes waste. In the UK, municipal solid waste (MSW) has been projected to grow at the rate of 2–3 per cent per year and hence by 2020 the annual MSW generated could have doubled; it currently stands at about 30 million tonnes per annum.

The UK through the European Union (EU) Directives has introduced measures to stimulate recycling and composting to reduce the amount of waste going to landfill, with demanding targets to be achieved. For example in Wales, the recycling target is 40 per cent by a combination of recycling and composting by 2010 with greater pressure to reduce the amount of biodegradable municipal waste (BMW) going to landfill such that by 2020 only 35 per cent of that produced in 1995 will be accepted. Alternative solutions need to be found to ensure that this target is met. If not, heavy financial penalties will be imposed. Thus engineering solutions are required to manipulate and treat waste. The drive is to consider this material as a resource where value can be extracted [**1**].

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## 2 WHAT IS WASTE?

Waste can be defined simply as anything that is no longer needed and that is thrown away. There are a number of legal definitions for waste, which include the following.

1. The EU defines waste as 'an object the holder discards, intends to discard or is required to discard' under the Waste Framework Directive [**2**].
2. The UK Environmental Protection Act 1990 indicates that waste includes

   > any substance which constitutes a scrap material, an effluent or other unwanted surplus arising from the application of any process or any substance or article which requires to be disposed of which has been broken, worn out, contaminated or otherwise spoiled; this is supplemented with anything which is discarded or otherwise dealt with as if it were waste shall be presumed to be waste unless the contrary is proved [**3**].

3. The UK Waste Management Licensing Regulations 1994 define waste as

   > any substance or object which the producer or the person in possession of it, discards or intends or is required to discard but with the exception of anything excluded from the scope of the waste directive [**4**].

The types of waste produced can be further classified in terms of the sector from which the waste is produced, for example municipal waste, industrial waste, construction and demolition waste, agricultural waste, and so forth.

## 3 WASTE MANAGEMENT LEGISLATION

The Environmental Protection Act 1990 (hereafter referred to as EPA90) set out the UK waste strategy and introduced Integrated Pollution Control. Integrated Pollution Control was based on the notion that the environmental impacts of a process on air, water, and land are viewed as a whole. Prior to this they were subject to separate controls. EPA90 is a framework act, which essentially means that the requirements of the Act will be implemented by a number of regulations. EPA90 introduced the notion of 'duty of care', which is essentially a measure to ensure the safe storage, handling, and transport of waste by authorized people and to authorized sites for treatment/disposal and was updated in 2005 [**5**].

The 1995 Environment Act established the Environment Agency and also introduced the principle of 'producer responsibility', its aim being to encourage the producer of a product to become more responsible for dealing with the waste produced due to the production of that product, and therefore increase the reuse or recycling of waste materials [**6**].

The EU also acts as a driver for UK legislation by the introduction of directives, which set out standards and procedures that must then be implemented in the member states, including the UK, via each member's legislative system.

The main EU measure was the 1975 Waste Framework Directive [**2**] as amended by the Framework Directive on Waste [**7**] and the Decision on Waste [**8**]. These directives require waste to be dealt with by measures that do not endanger the environment or human health; i.e. it set the foundation for sustainable waste management. The Waste Directive states that waste must be managed 'without causing a nuisance through noise or odours'. As a means of minimizing these environmental impacts, the Council Directive [**9**] on the Landfill of Waste (commonly referred to as the Landfill Directive) was introduced by the European Commission in 1999 and was transposed to UK law through the Landfill (England and Wales) Regulations 2002. The aim of this legislation is to prevent, or reduce as far as possible, the adverse environmental effects of landfill [**10**], hence the drive to provide engineering solutions that allow the extraction of value by means of a range of robust recycling options.

Furthermore, the requirements of the Landfill Directive include the following:

(a) sites are classified into three categories: hazardous, non-hazardous, or inert, depending on the type of waste they receive;
(b) biodegradable waste is progressively diverted away from landfills in line with the targets stipulated in the Directive; fundamental to this diversion are methods, processes, and markets to deal with this reduction;
(c) certain hazardous and other wastes, including liquids, are prohibited from landfills;
(d) pre-treatment of waste prior to landfilling is required after 16 July 2004 [**10**].

Again, methods and processes need to be robustly developed to cope with the changing demand with time.

The amount of biodegradable waste landfilled must be reduced in line with the following targets for the UK to comply with the Landfill Directive:

(a) to 75 per cent of the biodegradable waste produced in 1995, by 2010;
(b) to 50 per cent of the biodegradable waste produced in 1995, by 2013;
(c) to 35 per cent of the biodegradable waste produced in 1995, by 2020 [**10**, **11**].

The Landfill Directive has been implemented differently in each part of the UK. In Wales, it was implemented by means of the Landfill Allowance Scheme (Wales) Regulations 2004 [**12**]. Under this scheme, each Unitary Authority is allocated an annual allowance for the amount of BMW it can send to landfill within that period. This allowance declines year on year in order to comply with the Landfill Directive targets. A significant financial penalty exists for local authorities that exceed their annual allowance; this is set at £200 per tonne of BMW landfilled in excess of their annual target. In contrast, the English scheme as laid out by the Landfill Allowance Trading Scheme (LATS) Regulations 2004 [**13**] again sets an annual allowance for each Local Authority; however, English local authorities can trade their allowances in order to buy or sell as their needs require. Also, the financial penalties involved are more lenient than the Welsh regulations, at £150 per tonne of BMW landfill in excess of the annual allowance.

A number of EU Directives are in place, which target key wastes and industries, for example the Packaging and Packaging Waste Directive [**14**], the End of Life Vehicles Directive [**15**], and the Waste Electrical and Electronic Equipment Directive [**16**]. A number of key directives on issues such as biowaste and waste from extraction industries are also proposed, which affect the waste management industry. The proposed Biowaste Directive may enforce the separate collection of biowaste in order to maximize the use of composting and anaerobic digestion [**17**].

As a result of these regulations and targets and in particular the landfill regulations, the waste management industry in the UK will have to undergo a radical change in order to meet the targets required by law. The aim of these regulations is essentially to create a more sustainable approach to waste management, and a greater utilization of the waste hierarchy.

A waste hierarchy can be traced back to the 1970s: it was developed by the environmental movement, who argued that waste was made up of different materials and, as a result, the different fractions should be treated differently, i.e. some should not be produced in the first place, some should be re-used, some should be recycled and composted, some should be burnt, and some should be buried [**18**]. It was not until the 1991 'Waste Management Paper on Recycling' [**19**] that the waste hierarchy was officially recognized by the government. This version of the waste hierarchy is shown in Fig. 1. The waste hierarchy was then updated by 'making waste work' [**20**] to the version that is still used today (also shown in Fig. 1).

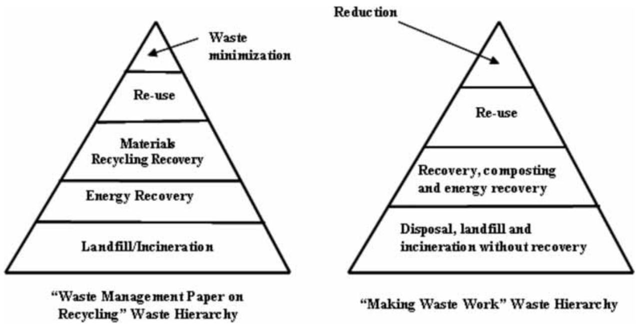


**Fig. 1** Waste hierarchy [**20**]

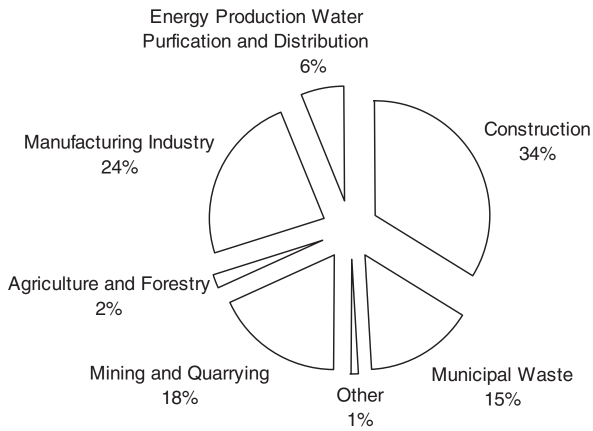


**Fig. 2** EU-15 waste composition by sector in 2002 [**21**]

## 4 WASTE AND RECYCLABLE MANAGEMENT AND ARISINGS IN THE EU

It is estimated that approximately 1.4 billion tonnes of waste are generated each year in the 15 member states of the EU (EU-15); these are the 15 member states in the period prior to enlargement in 2004, i.e. Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, the Netherlands, Portugal, Spain, Sweden, and the United Kingdom [**21**]. Figure 2 shows the proportion of different wastes generated per sector in 2002 in the EU-15. This figure highlights the fact that the construction and manufacturing industries account for 58 per cent while municipal waste accounts for only 15 per cent of the total waste arisings.

In 2005, it was estimated that each person in the EU generated approximately 534 kg of MSW per annum [**21**]. Generation was higher in the EU-15 states, however, at 574 kg per person per annum compared to the newer member states at 312 kg per person per annum [**21**]. Recently, the EU has shown a slight reduction in the waste generated to 522 kg per person; however, this reduction is not significant [**22**]. The management of this waste varies greatly between member states; this is highlighted in Fig. 3, which displays variations in MSW management across a selection of EU member states. It should be noted that the definition of MSW varies among member states; therefore, only broad comparisons can be made between countries.

Figure 3 clearly demonstrates that all the newer member states have a high reliance on landfill as a means of dealing with MSW; indeed, Bulgaria and Lithuania deal with 100 per cent of MSW in this manner. However, it is interesting to note that member states such as Greece, Ireland, the United Kingdom, Italy, Portugal, Spain, and Finland dispose of more

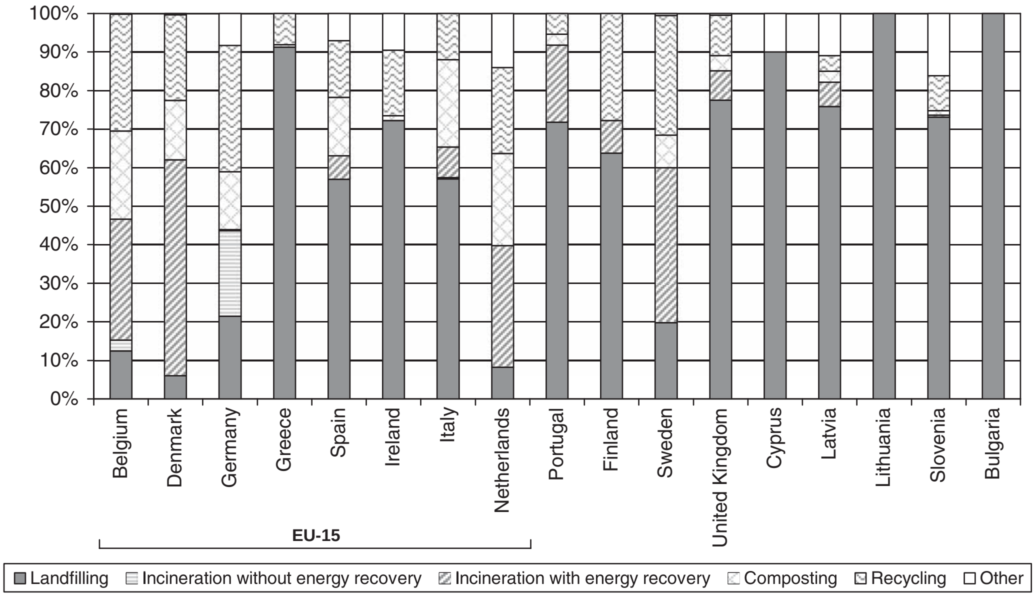


**Fig. 3** Variations in MSW management across Europe in 2005 [**21**]

than 55 per cent of their MSW to landfill compared with Denmark, Belgium, the Netherlands, Sweden, and Germany, which dispose of less than 25 per cent of MSW to landfill. In contrast to other member states, incineration is the main method of waste disposal in Denmark, with more than 50 per cent of their MSW being treated in that manner. Figure 3 also highlights the fact that Belgium composts or recycles the greatest proportion of its MSW stream, accounting for over 50 per cent, closely followed by the Netherlands and Germany, which both recycle and compost over 45 per cent of their MSW stream. It can also be seen that high recycling countries have high incineration rates.

The historic dependence on landfill in the UK has generally been due to low cost, availability, and its applicability for a wide range of wastes. However, the UK is simply running out of space and alternative solutions need to be found. Today, great strides have been made with landfill being reduced from 75 per cent in 2005 to 57 per cent in 2007 [**22**].

The composition of MSW varies considerably, due to factors such as socio-economic conditions, level of industrialization and type of industry present, geographic location, climate, population density, collection system, recycling systems present, public attitudes, etc. Seasonality also has a significant effect on composition, in that garden waste is greater in the summer months, which increases waste arisings. Tourism can also have a seasonal effect on MSW composition, e.g. influxes of tourists in the summer months to seaside resorts [**6**]. As a result of these effects along with lifestyle and cultural differences, MSW composition varies from country to country.

Figure 4 highlights the significant variation in MSW composition among a selection of EU member states. The organic fraction varies considerably, ranging from about 20 per cent in the UK, Ireland, and Finland to 51 per cent in Greece. Similarly, the paper fraction ranges from 8 per cent in Bulgaria to 43 per cent in Finland. The figure demonstrates that in the UK over 50 per cent of MSW consists of paper and organic material; the paper fraction is the main component (at approximately 32 per cent of MSW) followed by the organic fraction (which constitutes about 20 per cent), with the plastic and other waste fractions contributing to the bulk of the remaining material. In contrast, for the Netherlands paper and organic materials constitute the majority of the MSW stream at approximately 68 per cent: the organic fraction is double that of the UK at about 40 per cent, and the paper fraction constitutes a lesser fraction at about 28 per cent.

It is important to note that the definition of MSW varies between member states, which has an impact on compositional analysis undertaken; therefore, care must be taken when comparing member states. For example, in the UK waste from households accounts for 82 per cent of MSW; however, in Ireland waste from households accounts for only 58 per cent, and in Finland accounts for only 42 per cent [**21**]. This variation in composition will also dictate the treatment direction and engineering solutions required to reduce, reuse, and recycle the waste.

## 5 WASTE AND RECYCLABLE MANAGEMENT IN THE UK

It is estimated that in 2004 approximately 335 million tonnes of waste were generated in the UK; these data include 100 million tonnes of mineral waste from mining and quarrying, which is not defined as a controlled

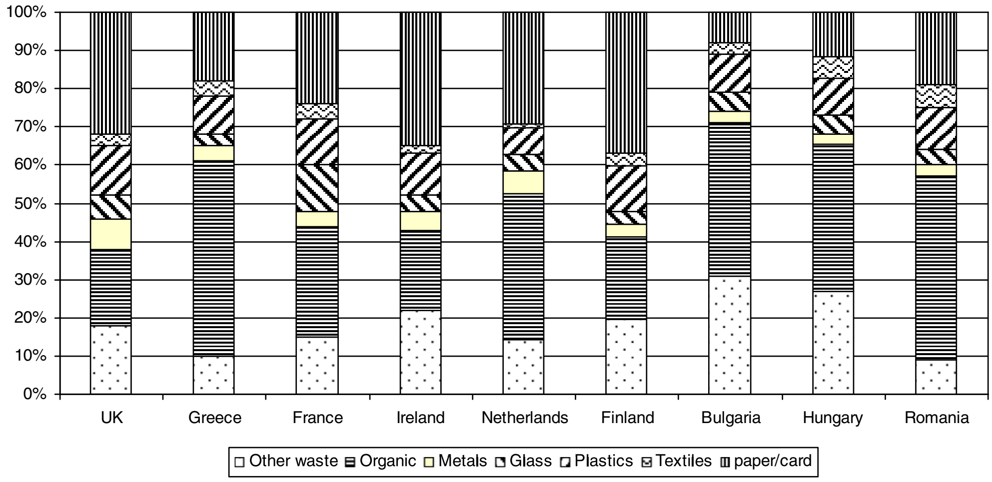


**Fig. 4** MSW composition for a selection of European countries [**23**]

waste (exempt from control by the EU Waste Framework Directive), and 220 million tonnes of controlled waste from households and industry. It must be noted that these figures do not take account of organic wastes such as manure and straw produced in the agricultural sector [**24**]. Figure 5 shows the proportion of various types of waste in the UK waste stream based on these data: household waste represents only 9 per cent of the total waste production, which is lower than the 15 per cent quoted for MSW for the EU-15 as a whole, as previously identified in Fig. 2.

This article focuses on MSW only, which consists of household waste and other wastes collected by a waste collection authority, e.g. some components of commercial or industrial waste and waste from public parks. The UK produces approximately 35 million tonnes of MSW each year [**25**]. Much of the MSW stream however may be reused, and therefore must be considered as a value resource for industrial production or energy generation.

The problem with waste management practices in the UK and in many other countries worldwide is that there is a mix and match of processes used to extract value. However, landfill is still the underpinning activity.

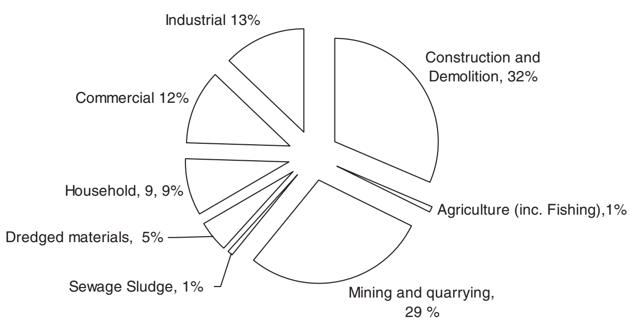


**Fig. 5** Estimated total annual waste arisings in the UK in 2004 by sector [**21**]

## 6 MSW CHARACTERIZATION IN THE UK

MSW should be treated as a resource because it contains many materials that can be reused or recycled, e.g. glass, metals, and paper along with other biodegradable material [**26**]. Table 1 shows the results of a variety of waste characterization studies that have been completed in the UK. The table was constructed using data obtained from four studies conducted in four regions of the UK: Rhondda Cynon Taf (RCT) County Borough Council, Carmarthenshire County Council, Cheshire, and the Wirral. It is clear that there are significant variations in the MSW between the four regions. For example, the paper and cardboard content ranges from 20 per cent in the Wirral to 37 per cent in Cheshire. This variation can be explained by the variations in socio-economic status of the areas, in that more affluent areas tend to read more newspapers and therefore generate a greater proportion of paper waste. Garden and kitchen waste varies considerably, ranging from 25 per cent in Cheshire to 39 per cent in the Wirral. Significant variation is also seen in the textiles fraction, with both Welsh regions (RCT

**Table 1** Examples of MSW composition in the UK [**27–29**]

| Category | RCT* (%) | Carmarthenshire (%) | Cheshire (%) | Wirral (%) |
|---|---|---|---|---|
| Paper and card | 25 | 32 | 37 | 120 |
| Garden waste | 11 | 33 | 14 | 17 |
| Kitchen waste | 19 | | 11 | 22 |
| Glass | 7 | 7 | 6 | 8 |
| Textiles | 4 | 2 | 6 | 7 |
| Ferrous metals | 4 | 3 | 3 | 3 |
| Non-ferrous metals | 1 | 1 | 1 | 1 |
| Plastics | 10 | 9 | 14 | 8 |
| Fines | 6 | 13 | 8 | 7 |
| Miscellaneous | 13 | | | 7 |
| Total | 100 | 100 | 100 | 100 |

*RCT–Rhondda Cynon Taf County Borough Council.

and Carmarthenshire) having a lower proportion (4 per cent and 2 per cent, respectively) than the English regions (with Cheshire and the Wirral having 6 per cent and 7 per cent, respectively). There is also a variation in the plastics component of the MSW stream across the four regions, ranging from 8 per cent in the Wirral to 14 per cent in Cheshire.

The BMW content of the MSW stream for the four regions also varies considerably. The data show that the two Welsh regions of RCT and Carmarthenshire had BMW contents of 55 per cent and 65 per cent, respectively, compared to the 61 per cent defined for Wales in the Landfill Allowance Scheme (Wales) Regulations. Therefore, the data in Table 1 suggest that Carmarthenshire has a greater pool of material to target in terms of BMW diversion, while RCT has less than the average Welsh figure. In comparison, the two English regions of Cheshire and the Wirral have BMW contents of 62 per cent and 59 per cent, respectively, compared to the 68 per cent BMW defined for England by the LATS Regulations. Hence, both regions have a lower pool of BMW to target for diversion, which suggests that these regions may struggle to comply with the LATS without having to trade allowances.

The composition of MSW varies as a result of a number of factors, including socio-economic status, geography, demographics, collection system, and so forth. This variation in composition can be observed on a number of scales, i.e. national, regional, and local, which further complicates waste management strategies as well as the technology required to either extract value or meet current regulations.

**Table 2** MSW generation for different household types [**6**]

| ACORN group | MSW arisings in 1991 (kg/hh/wk)* Range | Average | Projected average MSW arisings 2005 (kg/hh/wk)* (2% annual growth) |
|---|---|---|---|
| Agricultural area | 17.9–32.4 | 22.1 | 29.7 |
| High income, modern family housing | 9.6–21.5 | 14.3 | 19.2 |
| Older housing, intermediate income | 9.0–14.8 | 11.8 | 15.9 |
| Older terraced housing | 8.8–20.4 | 12.6 | 17.0 |
| Municipal housing, higher status | 10.7–23.3 | 14.6 | 19.6 |
| Municipal housing, intermediate status | 7.2–16.7 | 12.2 | 16.4 |
| Municipal housing, lower status | 7.2–17.6 | 13.6 | 18.3 |
| Mixed metropolitan areas | 5.0–12.3 | 9.8 | 13.2 |
| High status, non-family areas | 7.7–27.1 | 13.1 | 17.6 |
| Affluent suburban housing | 5.4–20.7 | 14.2 | 19.1 |
| High status retirement areas | 5.4–16.6 | 11.1 | 14.9 |

*kg per household per week.

## 7 FACTORS THAT AFFECT WASTE AND RECYCLE ARISINGS

One key factor that impacts waste composition and arisings is socio-economic status, i.e. the affluence of an area. This is highlighted in Table 2, which shows the results of a study carried out by the Department of the Environment as reported by Williams [**7**]. It is evident that generally the more affluent the area, the greater the amount of waste generated, e.g. the average MSW arising for terraced housing is 12.6 kg per household per week (kg/hh/wk), while waste for higher status municipal housing increases to 14.6 kg/hh/wk. Indeed it was found that average MSW arisings were greatest in agricultural areas at 22.1 kg/hh/wk. The information contained within this table essentially enables MSW arisings to be predicted for a particular area based on the 'A Classification of Residential Neighbourhoods' (ACORN) information for that area. The ACORN system is a demographic tool that categorizes each UK postcode based on census data [**30**].

However, it must be noted that the information contained in Table 2 does not take into account variations in the method of waste collection, e.g. the use of wheelie bins or the traditional dust bin, which can have an impact on waste generation. Also, it does not provide any information on compositional changes to the waste stream in relation to socio-economic status.

The data from the Department of the Environment study contained in Table 2 were published in 1991, and are therefore somewhat dated. Hence, the average data have been projected with an annual growth rate of 2 per cent to gain an indication of the data for 2005 in order to compare with the average Welsh MSW arisings figure for 2004–2005 of 24.3 kg/hh/wk [**31**]. From the table it can be seen that the projected average MSW arisings for 2005 ranged from 13.2 kg/hh/wk for a mixed metropolitan area to 29.7 kg/hh/wk for an agricultural area. It can also be noted that it is only the average figure of 29.7 kg/hh/wk that exceeds the 24.3 kg/hh/wk figure reported for Wales in 2004–2005, with all other projected average figures being below 19.6 kg/hh/wk.

Seasonality is another key factor that impacts waste composition and recycling. For example, garden waste is greatest during the growing season, and therefore has a significant impact on both arisings and composition [**32**]. The results of a study in 2002 found that the putrescible fraction of MSW increased from 30 per cent to 52 per cent between the winter and summer studies and is highlighted in Table 3. It is interesting to note that glass arisings are also higher in the summer.

The key to providing robust engineering solutions for waste management is realistic data. As illustrated in the previous discussion however, published information can be very general and more detailed analyses are required for design purposes. Tables 4 and 5 show

**Table 3** General composition of MSW in winter and summer [**33**]

| General components | % Winter | % Summer |
|---|---|---|
| Paper | 30 | 22 |
| Putrescibles (kitchen and garden) | 30 | 52 |
| Textiles | 5 | 2 |
| Glass | 16 | 12 |
| Metal | 11 | 6 |
| Plastic | 6 | 3 |

**Table 4** Household waste compositional analysis for urban and rural locations

| Category | Urban town A (%) | Urban town B (%) | Rural town C (%) |
|---|---|---|---|
| Newspaper | 5.6 | 6.3 | 5.5 |
| Magazines | 8.9 | 9.7 | 10.3 |
| Other paper | 10.5 | 6.4 | 6.6 |
| Glass | 6.0 | 6.8 | 6.2 |
| Ferrous metals | 2.7 | 2.7 | 3.3 |
| Non-ferrous metals | 0.9 | 1.0 | 2.2 |
| PET | 1.8 | 1.5 | 1.4 |
| HDPE | 0.8 | 0.4 | 0.8 |
| Other plastic | 9.8 | 11.8 | 9.1 |
| Garden | 1.8 | 1.4 | 2.4 |
| Kitchen | 25.4 | 26.3 | 18.1 |
| Textiles | 1.2 | 4.4 | 0.9 |
| Fines | 6.0 | 4.2 | 15.7 |
| Inert | 2.8 | 0.0 | 4.7 |
| Miscellaneous | 7.8 | 9.4 | 5.4 |
| Card | 8.0 | 7.7 | 7.6 |
| Total | 100.0 | 100.0 | 100.0 |

**Table 5** General overview of the urban and rural locations

| Overview | Urban town A | Urban town B | Rural town C |
|---|---|---|---|
| Set out (%) | 57.1 | 75.0 | 75.0 |
| Recycling rate (%) | 25.1 | 30.1 | 29.5 |
| Household waste generated kg/hh/wk | 10.2 | 9.88 | 14.83 |

the results of a recent detailed household waste characterization analysis for urban and rural locations undertaken by the authors, thus allowing availability of specific waste streams to be assessed in terms of the likely tonnages presented to an engineered facility. Table 5 shows the variability that can occur in the participation of the various households and the recycling rate and supports the earlier findings that arisings are higher in rural areas [**6**].

## 8 ENGINEERING VALUE RECOVERY

### 8.1 Overview

Figure 6 gives a schematic overview of an integrated approach to waste management. MSW can be initially offloaded to a recovery facility usually called a 'material recovery facility' (MRF) or a mechanical biological treatment plant [**34**]. The bulk of the plants in the UK are of an MRF design taking either presorted or co-mingled waste and are usually classed as 'clean' or 'dirty' streams. The design and operation of such plants are highly dependent on the incoming material. Generally the primary separation is flexible to allow diversions into a number of downstream processes (Fig. 6). The unit operations employed in processing recyclable materials include size reduction, magnetic separation, screening, size reduction, air classification, eddy current separation, can flattening and densifications, and baling [**35**]. This flexible approach allows for market and quality fluctuations. Operators of MRFs do not always supply directly to the businesses that use the recyclate. Often agents are used as a third party to ensure that demand is consistent. This can often lead to issues such as supply, cleanliness, and quality. Furthermore, knowing the marketplace in terms of the prices obtained for the various streams can indicate the returns that can be made based on an investment strategy related to the types of waste. Table 6 gives a typical example of some of the prices that are currently being achieved. However, these prices have experienced fluctuations during the last 12 months, e.g. aluminium cans generated £700/tonne during 2007–2008, but as Table 6 shows one re-processor is currently only achieving £300/tonne.

There is no one solution that fits all in waste management; it is a question of assessing what is required to meet relevant legislation and national targets, and assessing local conditions and needs. In most cases an integrated waste management programme that incorporates a combination of treatments, including energy recovery, composting, and recycling, is used to fulfil the needs required [**36**].

### 8.2 Dirty versus clean MRF scenarios

Clean MRFs are facilities that recover material for recycling from source-segregated mixed dry recyclates. The incoming material may be presented in a number of different formats that can be grouped as follows:

(a) single stream, i.e. mixed paper, cardboard, and containers, which may or may not include glass;
(b) two stream, i.e. one stream containing paper and cardboard, and the other containing mixed containers, which are then fed into different locations in the MRF.

As well as the above, material can also be presented to the MRF bagged or loose.

Typically clean MRFs recover in excess of 90 per cent of the feedstock. There will always be some material that is rejected, e.g. material such as some types of plastics that cannot be easily recycled and therefore go to landfill.

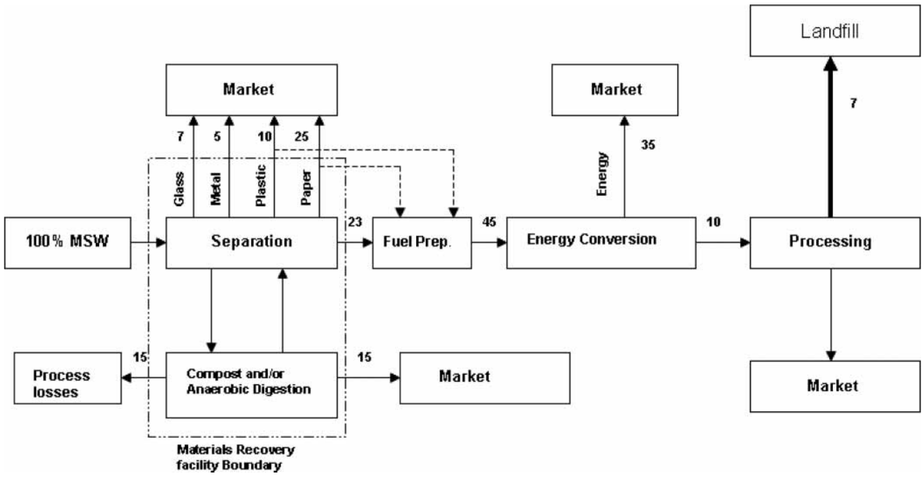


**Fig. 6** Integrated solution to waste management with typical flows [**37**]

**Table 6** Typical recyclate prices for 2009 [**38**]

| Stream | Value £/tonne |
|---|---|
| Paper | 30 |
| Aluminium cans | 300 |
| Ferrous metals | 28 |
| Plastic bottles | 90 |

The advantages of a clean MRF are the following:

(a) recovery of higher quality materials for recycling as the material is free from food waste, etc.;
(b) high processing efficiency;
(c) health and safety conditions within a clean MRF are generally better than in a dirty MRF;
(d) proven around the world.

The disadvantages of a clean MRF are the following:

(a) a source segregated kerbside collection system is needed to provide the feedstock required for the MRF; hence, there are increased collection rounds with the associated impact on traffic movement and air quality;
(b) the performance of the MRF is highly dependent on participation within the kerbside scheme.

Dirty MRFs are facilities that recover recyclable material from MSW directly [**39**]. Some more advanced facilities may also recover biodegradable material that may be sent for anaerobic digestion or in-vessel composting, or a high calorific value stream that can be converted to produce a refuse-derived fuel (RDF). Typically a dirty MRF can recover approximately 15–20 per cent as dry recyclates, which are then sold to reprocessors.

The advantages of a dirty MRF are the following:

(a) a dirty MRF utilizes the existing MSW collection infrastructure; hence, collection rounds are unchanged and environmental impacts in terms of air quality and transportation remain the same;
(b) performance is not dependent on householder participation as householders are not required to change their behaviour; therefore, participation in the scheme is 100 per cent by definition.

The disadvantages of a dirty MRF are the following:

(a) contamination of potentially recyclable material with food waste, garden waste, etc., has an impact on the performance of the MRF;
(b) generally lower income is obtained for the sale of recovered recyclables as they are generally of lower quality;
(c) use of dirty MRFs does not encourage householders to change their behaviour in terms of waste minimization and recycling.

### 8.3 Conceptual MRF design

In any MRF, the key to a successful operation is process flexibility; as during the operational life of a facility many changes are likely, e.g. in waste composition, waste collection methods, material presentation, and so forth. There are also examples where hybrid systems operate so that campaigns can operate in either ‘clean or ‘dirty’ modes. Also, process flexibility would allow other materials to be processed without significant changes. Hence, it is vitally important to consider these factors in the design. At the moment it is not possible to eliminate manual sorting and its integration is important. For example, Table 7 gives an indication of the reaction times for selecting various materials from a mixed stream and Table 8 highlights the typical quantities that a sorter can be expected to remove per hour. Both aspects are important factors in the design of any engineered recovery system. Hence the decision of whether to segregate materials manually or automatically will depend on the volume and return of the particular streams.

A review of 16 MRFs was undertaken by the authors in the UK and overseas: 12 were ‘clean’ and four were

**Table 7** Reaction times for various material types in different stream types [**40**]

| Material mix | Target material | Reaction time (s) |
|---|---|---|
| Metals/plastics/paper and card | PET | 1 |
| | Paper | 3 |
| | Card | 3 |
| | PVC | 2 |
| Paper and card | Paper | 2 |
| | Card | 2 |
| Mixed plastics | PET | 1 |
| | PVC | 3 |
| | Plastic film | 2 |

'dirty'. Detailed analyses of these sites were undertaken and summary activity tables were constructed, examples of which are given in Table 9 for a UK 'clean' MRF operation and in Table 10 for a USA 'dirty' MRF operation.

Using this analysis the basic operation can be broken down into three key components as identified in Fig. 7 [**41**]. The first component is the material preparation phase, where essentially the feedstock is prepared to allow for effective separation. Processes that are undertaken include bag splitting, debaling, and presorting to remove any large objects, etc. The extent of the material preparation phase is highly dependent on the nature of the feedstock material.

**Table 8** Sorting rates per person for various material types [**40**, **42**, **43**]

| Material | Sorting rate (kg/h) per person |
|---|---|
| PET | 160–250 |
| Paper | 680–4545 |
| Card | 680–4545 |
| PVC | 240 |
| Glass | 409–818 |
| Plastic Film | 20–36 |
| Textiles | 180 |

The second component is the primary separation phase, whereby crude separation is undertaken in order to make the final material recovery phase more effective and efficient. The primary separation phase varied significantly between plants. In 'clean' MRFs, a simple disc screen that separates components into 'two-dimensional (2D)' (paper, card, and plastic film) and '3D' (plastic bottles and cans) streams might suffice, while in dirty MRFs, the primary separation phase tends to be more complex. The primary separation phase in dirty MRFs ranged from the use of kinetic streamers, trammels, and vibrating screens to the use of ballistic separators. The remaining processes are again component separation devices.

The final material recovery phase essentially is the separation of materials required for reprocessing, the extent of which is highly dependent on market conditions but also on the type of segregation utilized. Segregation can be either manual or automated. There is no formulated rule base to say when a facility should be fully automated or not. Many other factors such as labour costs, capitalization, and throughput will have an impact on the decision making process. Fully automated operations will consist of sorting equipment such as overband magnets (steel), eddy current separators (aluminium/copper), optical sorters (plastics), and air classifiers, glass, and lighter fractions.

Figure 8 highlights a conceptual design for an MRF and identifies the three component phases of the process as shown in Fig. 7 [**41**]. The material preparation phase indicated by the letter A in Fig. 8 consists of a presort station and bag opener. At the presort station, bulky items are removed and the remaining material then continues to a bag opener, which opens any bagged material and liberates the contents. The addition of a bag opener within the conceptual design enables the MRF to be more flexible in terms of the feedstock processed, as loose and/or bagged material could be processed.

**Table 9** Summary of a UK 'clean' recycling MRF operation [**41**]

| | | | |
|---|---|---|---|
| MRF type | Clean | | |
| Equipment manufacturer | Bulk handling systems (BHS) | | |
| Throughput | | | |
| Design capacity (tph) | 10 | | |
| Actual capacity (tph) | 8 | | |
| Number of pickers per shift | 20 | | |
| Residue (%) | 11 | | |
| Material type | Currently processes | Could process | Could not process |
| Clean stream | | | |
| Single stream material (excluding glass) | √ | | |
| Single stream material (including glass) | | | √ |
| Two stream material – paper and containers | √ | | |
| Bagged material | √ | | |
| Loose material | √ | | |
| Baled material | √ | | |
| Dirty material, i.e. MSW | | | √ |
| Commercial recyclable | √ | | |

**Table 10** Summary of a ‘dirty’ MRF operation [**41**]

| | | | |
|---|---|---|---|
| MRF type | | Dirty | |
| Equipment manufacturer | | Miscellaneous | |
| Throughput | | | |
| Design capacity (tph) | | 134 | |
| Actual capacity (tph) | | 100 | |
| Number of pickers per shift | | 35–40 | |
| Residue (%) | | 65 | |
| Material type | Currently processes | Could process | Could not process |
| Clean stream | | | |
| Single stream material (excluding glass) | | √ | |
| Single stream material (including glass) | | √ | |
| Two stream material – paper and containers | √ | | |
| Bagged material | √ | | |
| Loose material | √ | | |
| Baled material | | | √ |
| Dirty material, i.e. MSW | √ | | |
| Commercial recyclable | | √ | |

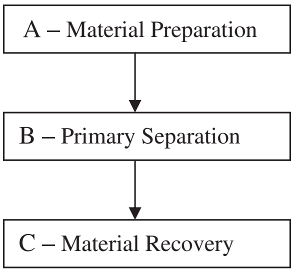


**Fig. 7** Key components of MRF processes [**41**]

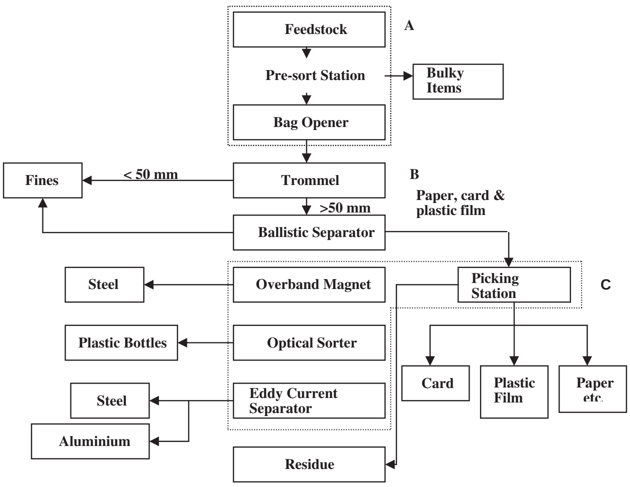


**Fig. 8** Conceptual MRF design flowchart highlighting process components [**41**]

The primary separation phase identified by the letter B consists of a trommel and ballistic separator (a ‘2D’/‘3D’ device). The material from the bag opener enters a trommel, which screens and removes the finer fraction of the feedstock, e.g. organic material, bottle tops, shredded paper, broken glass, and so forth. The inclusion of a trommel screening at an aperture size of say 50 mm within the conceptual design enables the MRF to process household waste (dirty stream), which contains a large organic fraction, and thereby clean the recyclable components contained within the waste stream.

The oversized fraction from the trommel then continues to a ballistic separator. The ballistic separator sorts material by shape and weight, and hence splits the material into two streams: a 2D and light material stream, such as paper, cardboard, plastic film, fines, etc., and a 3D and heavy material stream, namely containers, for example.

The material recovery phase consists of a picking station to manually sort the 2D stream segregated by the ballistic separator or any other similar device and an over-band magnet, optical sorter, and eddy current separator to segregate the 3D stream.

At the sorting station, operatives manually segregate paper, cardboard, and plastic film, and any material that is not picked is a residue from the process and is sent for disposal. Depending on the incoming feedstock, the picking regime at this stage could be altered; e.g. if the incoming material had a high proportion of newspapers, a negative picking action could be utilized at this stage. That is, pickers would remove any material that was not newspaper in order to clean that particular material stream.

The container (3D) stream from the ballistic separator then continues to a series of automated unit operations, these being an over-band magnet to remove steel cans from the stream, an optical sorter to remove mixed plastic bottles, and an eddy current separator to remove the aluminium stream and also to remove any missed steel. Any remaining material is sent for disposal.

This design is flexible in that a variety of materials can be processed:

(a) single-stream dry recyclable that is either loose or bagged;
(b) MSW;
(c) two-stream dry recyclable that is either loose or bagged.

**Table 11** Performance of a hybrid MRF [**41**]

| Component | Percentage to selected products | |
|---|---|---|
| | Clear bags | Black bags |
| Paper and card | 36 | 20 |
| Glass | 0 | 23 |
| Ferrous metals | 98 | 60 |
| Non-ferrous metals | 86 | 39 |
| Plastics | | |
| Bottles | 67 | 59 |
| Film | 31 | 31 |
| Other | 0 | 0 |

To further improve process flexibility, other feed points could include:

(a) loose mixed containers fed into the plant onto the container line after the ballistic separator;
(b) loose mixed paper fed into the MRF onto the paper, cardboard, and plastic film line after the ballistic separator.

Hence, if there were any changes to the collection operation, these could be handled without the need for significant changes to the process. Also, as the paper and card are manually sorted, any changes in these markets could be readily addressed by instructing pickers to sort in a different manner.

The authors have undertaken analyses of a hybrid MRF campaigning clear and black bag residue without 2D/3D steaming. Table 11 shows the performance data.

It can be seen from the table that for the clear stream there was a high recovery of ferrous and non-ferrous metals and a reasonable separation of plastic bottles. These are the high value components. The paper and card recovery in the 'clean' mode was disappointing, and could be a function of the presentation of the component to the MRF. When campaigning in the 'dirty' mode with residual black bag waste, the recovery dramatically reduced the metals fraction. Also present is a high glass fraction that is unwanted when in the manual sorting mode.

## 9 CONCLUSIONS

Legislation is driving the waste industry to recover value and volume from a number of streams that make up MSW. One of the key components of any integrated approach to waste management is the MRF. This allows the generation of specific components that can be sold into the marketplace. The design of MRF facilities is fundamentally important to ensure that recovery operations meet the recycling requirements of the incoming waste materials. The drive is to ensure quality and cleanliness can be maintained at realistic costs. Providing robust data is the forerunner to a proper engineering solution for value recovery.



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