AN ENERGY AND MATERIALS FLOW MODEL FOR EVALUATION OF ALTERNATIVES FOR PROCESSING DOMESTIC AND COMMERCIAL WASTES – A CASE STUDY OF SOUTHAMPTON

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EXECUTIVE SUMMARY

Waste continues to be produced in large quantities and the rate of increase in production is more or less in line with the rate of growth in the economy. How can this waste best be managed? European legislation such as the Landfill directive has been derived on the basis of sustainability, resource recovery and, importantly, reducing greenhouse gas emissions. What is our strategy for achieving these goals, and on what basis can we make long term plans? Strategic waste management decisions are still based on costs and targets, but the sustainability of certain practices is in question.

One of the best ways to assess sustainability is in terms of mass and energy balance. A project was recently undertaken at the University of Southampton to look at the 'Energy Footprint' for waste management. The project brings together data from existing work on waste quantities, materials flow and mass balance studies for a range of materials including glass, paper, plastics, metals and organics. These data are combined with information on the energy requirements for different types of collection and processing systems for re-use, recycling, recovery and disposal of such materials. Taking into account energy benefits from any of these options, the information is used to produce an energy and materials balance, and the results show the energy footprint and materials output of the current waste management practices in Southampton. The work also allows exploration of alternative methods and highlights areas where improvements in collection or processing technologies could have a significant impact on the final energy and material balance. The greater Southampton area (in the county of Hampshire in the UK) is used as a case study, but the methods developed can also be applied to other areas by modifying the input data.

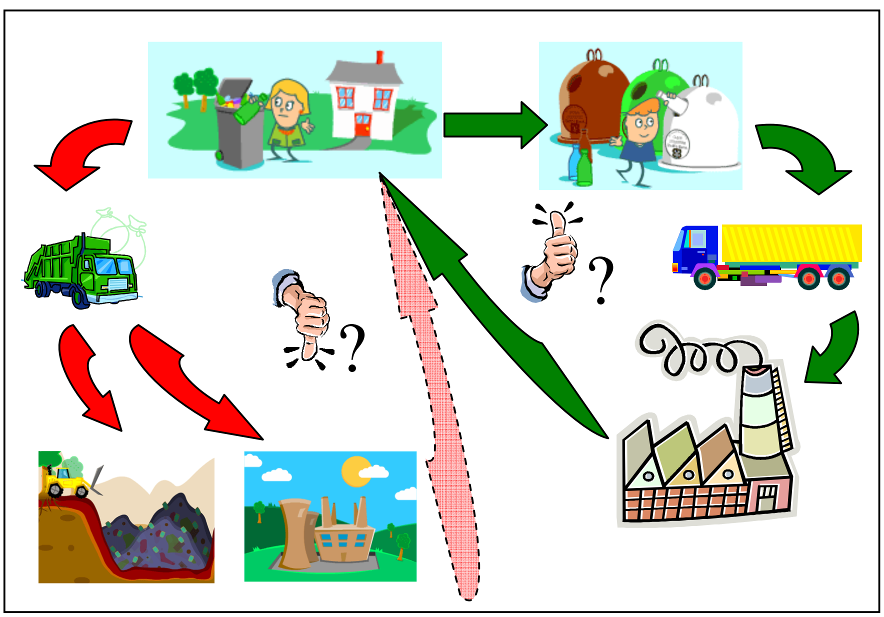

Figure i: Simplified diagram of MSW management

The Energy Footprint Model starts from the point where material leaves the household, and follows it through until disposal and/or reprocessing. This is represented in Figure i, which shows a simplified diagram for MSW waste management. On the left are the disposal (landfill) and alternative waste treatment routes (for example, incineration). Although these routes are the more traditional ones, they are considered to be the least favourable; whereas recycling and re-use have been thought of as preferred waste management options (after minimisation). This route is indicated on the right of the diagram using glass as an example, showing the collection, transfer and manufacturing stages of the recycling cycle.

Although recycling enhances sustainability with regard to raw materials, does it also promote sustainable energy practices? There is an inherent energy consumption associated not only with the processing of the recycled materials, but also transporting the materials from point A to point B. Is this energy consumption greater than any savings made through use of recycled material for manufacture of new materials? The Energy Footprint Model focuses on answering this question, by determining the energy consumption for the different stages of waste disposal/treatment and recycling.

The Energy Footprint Model is compiled in Microsoft Excel and Visual Basic and is constructed from individual inter-linked sub-models. Most of these sub-models are generic, in that they can be applied to all of the waste fractions, with appropriate changes to the input parameters. Some sub-models are material specific, however, e.g. glass manufacture, plastics reprocessing, etc. The main generic sub-models that are used to determine the energy consumption for each stage of the transfer of the material from the household to its final destination are as follows:

Disposal/Alternative Treatments:
- Refuse collection and landfill transfer
- Incineration

Recycling:
- Stage 1 transport
- Kerbside collection
- Material manufacturing/processing facility
- Stage 2 transport
- Material Recovery Facility

The route for the disposal/alternative treatment of the waste is fairly straightforward: collection of the waste from the household, followed by transfer to the landfill site or treatment facility, e.g. incinerator.

The recycling route is more complex, however, and has more stages, some of which are material specific. Firstly, collection can either be via bring-sites or via a kerbside collection scheme. In the model, the Stage 1 and 2 transport sub-models are associated with recycling via bring-sites and Household Waste Recycling Centres (transfer to, and from these facilities, respectively).

After collection the material is then transferred to a manufacturing/processing facility where it is used to make new materials. The routes and number of steps between the collection stage and manufacturing stage are very much dependent upon the material being recycled and/or the recycling collection method. For instance, recycled glass is first taken to the new sorting/crushing facility located at Southampton Docks. From here it can be sent (often initially by ship) to a glass manufacturing plant or elsewhere, for alternative uses, e.g. aggregates replacement.

In contrast, mixed dry recyclables (paper/card, plastic bottles/containers and metal cans) collected via the kerbside collection scheme in Southampton are first sent to a Materials Recovery Facility for sorting/separation before being transferred to the manufacturing/processing facility.

SOUTHAMPTON WASTE GENERATION

The model uses waste generation and recycling data from the period 2000 – 2002 (where available) for the base-case scenario energy consumption calculations. The estimated amounts of waste generated and material recycled for the different waste categories are given in Table i.

Waste Category	amount generated [tonnes/yr]	wt %	amount recycled [tonnes/yr]	recycling rate [%]
Paper & card	23562	26.02	4265	18.1
Plastic Film	6658	7.35	0	0.0
Dense Plastic	4981	5.50	53	1.1
Textiles	4538	5.01	213	4.7
Misc. Combustibles	5370	5.93	142	2.6
Misc. non-Comb.	1707	1.89	729	42.7
Glass	5326	5.88	1376	25.8
Ferrous Metals	3792	4.19	1047	27.6
Non-ferrous metals	876	0.97	49	5.6
putrescibles	24187	26.71	1543	6.4
fines	3235	3.57	0	0.0
Sub-Total	**84232**	**93.01**	**9417**	**11.2**
Miscellaneous	6335	6.99	177	2.8
TOTALS:	**90567**	**100.00**	**9594**	**10.6**

Table i: Household Waste in Southampton (base-case scenario)

The Energy Footprint Model presently focuses on the management of the five main waste fractions: Glass, Paper/Card, Plastics, Metals, and Organics. Together, these materials constitute ~78 % of the household waste generated (83 % of the main categories, excluding "miscellaneous"), and ~89 % of the total material recycled.

GLASS WASTE FRACTION

Figure ii shows the effect of glass recycling on the energy consumption of the different stages associated with recycling, processing and disposal of the glass waste. In this scenario, the glass is recycled via bottle banks only. It can be seen that there is a linear increase in the energy consumption associated with the recycling (collection, processing and transfer) stages. This is simply because, as more glass is recycled, the number of trips and collections etc. required (for a fixed bottle bank density) to transfer this material from point A to B increases proportionately. Similarly, energy consumption for the disposal of the residual waste stream decreases (linearly), since proportionately less material requires disposal.

The increases/decreases are linear because it is assumed that the increases in recycling rate can be achieved with the existing infrastructure (base-case scenario, represented by the dashed vertical line). In reality, this will not be the case and an increase in recycling would generally only be achieved with changes to the infrastructure: for example, an increase in the number of bottle banks located throughout the city.

It can be seen that the manufacturing process ("glass furnace") for glass is energy intensive. It is here, however, that the greatest energy savings can be made through the increased use of recycled glass in manufacturing. Indeed, any increases in energy consumption due to increased recycling are offset by the relatively large energy savings from using cullet in glass manufacture. The results show that the maximum savings in energy is 6.6 % compared to the base case scenario (25.8 % recycling rate).

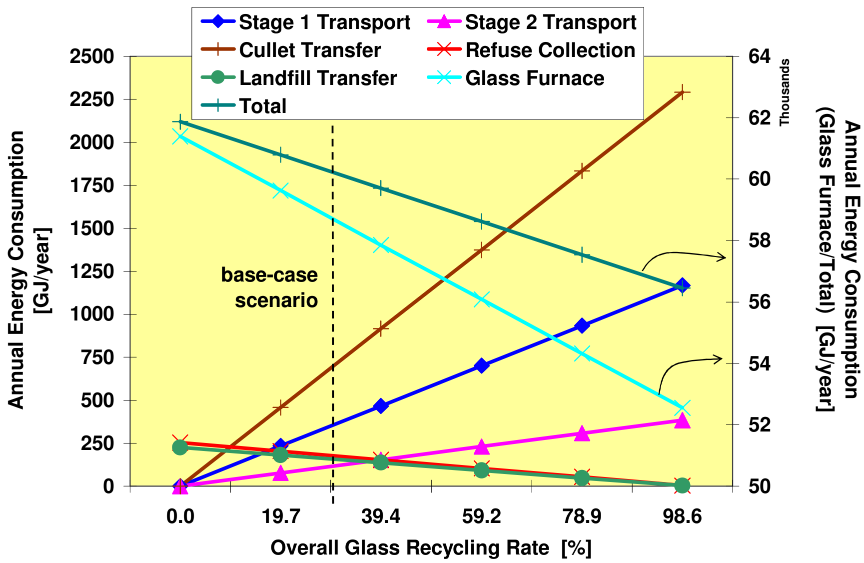

Figure ii: Effect of Glass Recycling on Energy Consumption

Collection Methods

In addition to examining the effect of increased recycling via bottle banks, the effect of recycling via a kerbside collection scheme was also modelled. Figure iii shows the effect of the gradual introduction of a kerbside collection scheme throughout the city. It is assumed that the inhabitants in those areas that operate the kerbside scheme do not recycle via bottle banks. Conversely, those areas that do not have the kerbside scheme recycle via bottle banks with the same recovery rate as the base-case scenario (26.2 %; equivalent to an overall recycling rate of 25.8 %). Then the effect of increasing the recovery rate via the kerbside scheme is examined.

The results show that, as the coverage and recovery rate of the scheme is increased, the energy consumption decreases to a minimum for a 100% recovery rate with city-wide coverage. This effectively represents complete replacement of the bottle banks with the kerbside scheme. Indeed, introduction of the scheme would increase the energy savings (compared to the base-case scenario) from 6.6% (bottle banks) to 8.4% with kerbside collection. Also, at low kerbside recovery rates the energy consumption is higher than the base-case scenario (coverage = 0%). This is because where the kerbside recovery rate is less than the bottle bank recovery rate (fixed at 26.2%), less glass is recycled, so the energy consumption is higher. In reality, however, it is unlikely that the recovery rate from a kerbside collection scheme would be lower than the recovery rate from collection via bottle banks.

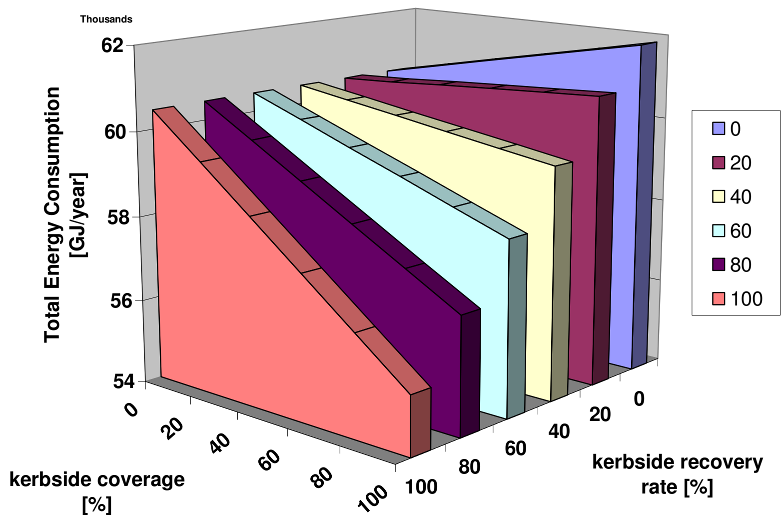

Figure iii: Effect of Introduction of a Kerbside Collection Scheme

Options for use of Recycled Glass

There is presently a diversification in the use of recycled glass, with diversion away from the traditional use in glass manufacture into areas such as aggregates replacement, filtration systems, sand-blasting etc. An example of the effect of this is shown in Figure iv. For this scenario, recycling is via bottle banks only, and the amount of recycled glass being diverted for use as aggregates is then varied. The model assumes that the diverted cullet is transported 25 miles to its point of use (for example in local road construction).

The graph shows that with no diversion of recycled glass the total energy consumed decreases with an increase in the recycling rate. In contrast, at 100 % diversion, the energy consumption actually increases as the level of recycling is increased. This is because the energy savings made through use of recycled glass in the manufacturing process are removed when glass is diverted for use as aggregates.

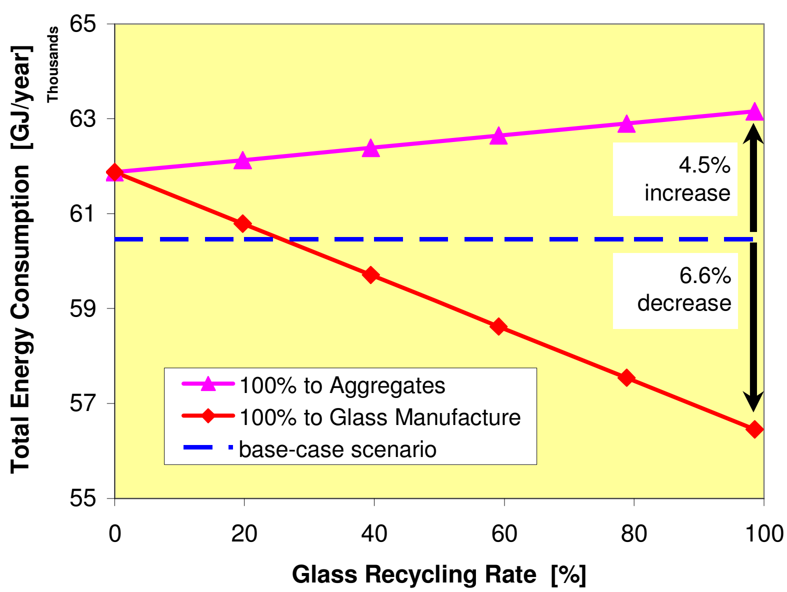

Figure iv: Comparison of Options for use of Recycled Glass

Hence, in terms of energy consumption it would not be desirable to divert collected glass away from use in glass manufacture. It should be noted, however, that the determination of the consumption for both scenarios does not include that for the mining etc. of raw materials used in glass manufacture or for traditional aggregates. Thus, the results may vary somewhat if this is included in the glass waste chain/cycle; although it is expected that the use of recycled glass in manufacturing would still provide the best 'energy' option.

Recycling versus Incineration

Incineration is an option for waste management and is therefore considered for the glass waste chain/cycle. This is certainly necessary for the Southampton area, since a new waste incineration plant is due to come online in early 2005. As glass is inert, however, its incineration actually consumes energy because it does not contribute to the energy produced, takes in heat, and would require landfilling/disposal after it has been incinerated. Hence, it would be expected that glass recycling would directly impact on the incineration of the residual waste, just as it impacts on refuse collection, landfill transfer, etc. Figure v shows the effect incineration has on the energy consumption, and compares the following three scenarios:

1) recycling of the glass via bottle banks with variable recycling rate, and landfill of the residual waste stream
2) no recycling of the glass, and variation of the level of incineration of the residual waste stream (with landfill of the remainder)
3) recycling via bottle banks with 100 % recovery rate and variable incineration

The graph shows that compared to 'recycling-plus-landfill', 'no-recycling-plus-incineration' of the residual waste stream gives a much lower energy consumption, as would be expected. Indeed, at an incineration level of approximately 20 % the energy produced from incineration of the residual waste offsets the energy consumed from glass manufacture and other aspects of the glass waste chain/cycle. Above this level of incineration there is a net energy gain.

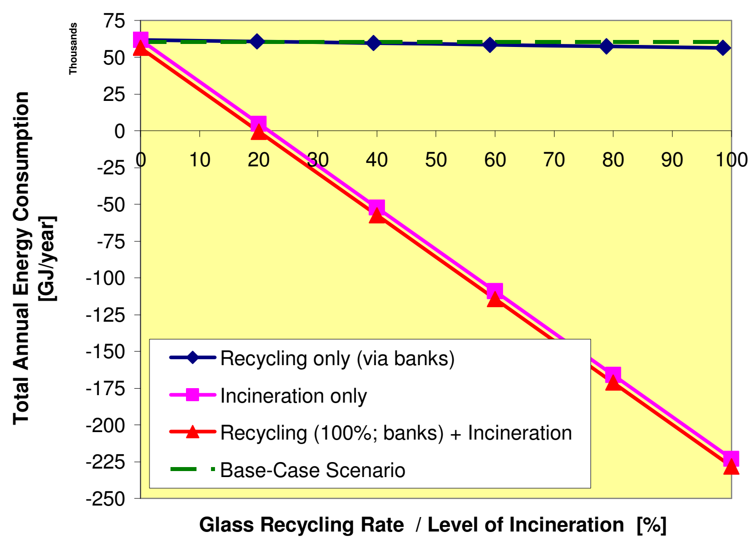

Figure v: Effect of Incineration on Energy Consumption (Glass Fraction)

The results above suggest that, in terms of energy consumption, it would be better not to recycle glass and simply to incinerate the residual waste stream. The graph also shows, however, that a combination of maximum recycling of glass combined with incineration of the residual waste consumes less energy than the 'incineration-only' scenario. This is firstly because recycling reduces the energy consumption associated with the glass waste chain/cycle. Secondly, the effect that glass recycling has on incineration of the residual waste is not a detrimental one. This is because, although recycling reduces the amount of waste available for incineration, it increases the calorific value of the residual waste

PAPER/CARD WASTE FRACTION

Collection Method

Here, the collection of paper/card from two different kerbside collection schemes is examined: a) the PaperChain scheme, which collects newspapers and magazines only and b) the dry recyclables scheme, which collects recyclable paper and card together with plastic bottles/containers and metal cans. Figure vi shows the progressive replacement of the PaperChain scheme with the dry recyclables scheme, which is effectively what is happening within Southampton at present. For this scenario, however, it is assumed (for simplicity) that there is no material recycled via paper and card banks.

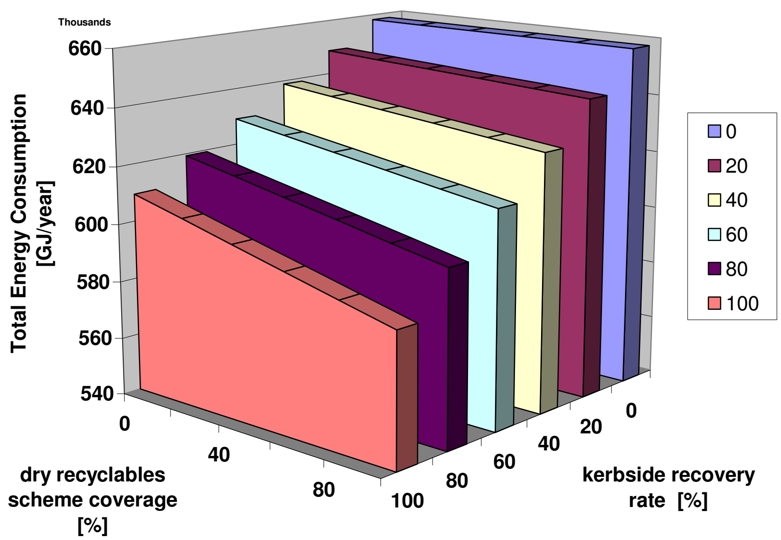

Figure vi: PaperChain versus Dry Recyclables Scheme

The results show, as expected, that the total energy consumption decreases with an increase in the kerbside recovery rate, since the amount of material collected for recycling increases. It is only at relatively high recovery rates, however, that the energy consumption decreases significantly as the proportion of the population covered by the dry recyclables scheme is increased. This is because although the dry recyclables scheme collects more material than the PaperChain scheme (for a given recovery rate), there is an energy consumption associated with the sorting of the dry recyclables at a MRF. In addition, there are losses associated with the sorting at the MRF. Hence, less material is sent to the paper mill than is actually collected for recycling. Thus, more energy is required for paper manufacture than for the same amount of material collected via the PaperChain scheme.

Therefore, it is not until high recovery rates that sufficiently more material is collected via the dry recyclables scheme (as the percentage coverage increases) than is collected via the PaperChain scheme at 100 % PaperChain coverage. At this point the energy consumption will be less, since more recycled material is now being used in paper manufacturing. Hence, if high recovery rates can be achieved, then recycling via the dry recyclables scheme is better than via the PaperChain scheme. The energy savings (compared to the base-case scenario) with maximum recycling via the PaperChain scheme are 4.9 %, increasing to 8.7 % with maximum recycling via the dry recyclables scheme.

Recycling versus Incineration

The effect that incineration has on the energy consumption associated with management of the paper/card waste fraction is examined by looking at various scenarios as follows:

1) recycling of the paper/card via bring-site/HWRC banks only, with variable recovery rate and landfill of the residual waste stream
2) no recycling of the paper/card, and variation of the level of incineration of the residual waste stream (with landfill of the remainder)
3) recycling via the paper/card banks with a 100 % recovery rate and variable levels of incineration
4) recycling via the dry recyclables scheme with a 100 % recovery rate and variable levels of incineration

The total energy consumption associated with each of these scenarios is shown in Figure vii. Firstly, it can be seen that, compared to scenario 1 (recycling-plus-landfill), scenario 2 (incineration-only) gives a much higher maximum reduction in energy consumption: 44.6 % over the base-case scenario (dashed line) compared to only 8.75 %. Because of the large energy consumption associated with paper manufacture (cf. glass waste fraction) there is not, however, a point where there is a net energy gain.

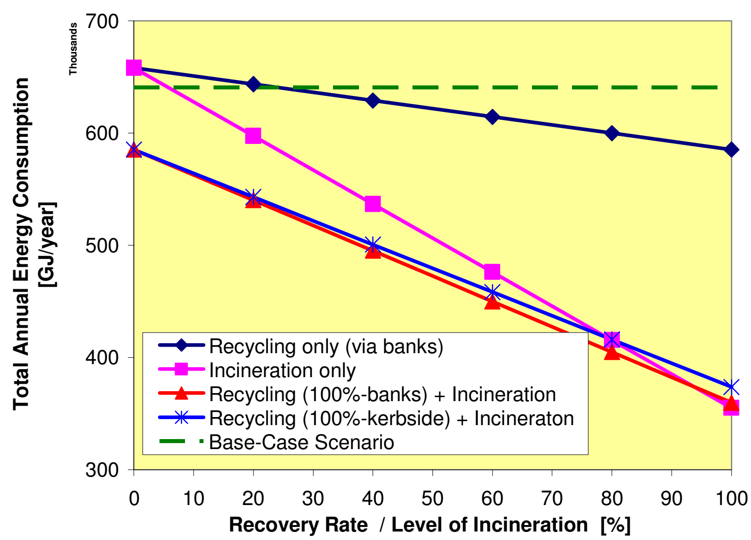

Figure vii Comparison of Recycling and Incineration (Paper/Card Fraction)

Secondly, at levels of incineration of up to ~ 80 % (for scenario 3) or ~ 95 % (scenario 4), the scenario of recycling (100 %) plus incineration gives a lower energy consumption than the incineration-only scenario. At higher levels of incineration, however, the opposite is true.

This is generally because although recycling reduces the energy consumption associated with the paper and card waste chain/cycle, it also affects the amount and calorific value of the residual waste stream. The magnitude of these affects is, however, dependent on the scenario examined as indicated below.

For scenario 3, where there is recycling via the paper/card banks, the amount of material recycled is relatively high. Hence, the reduction in energy consumption due to recycling is fairly large. In addition there will be a relatively high amount of energy produced from incineration, since a limited amount of material is removed from the refuse compared to scenario 4. This is slightly offset, however, by the small decrease in the calorific value of the residual waste stream. Thus the overall affect is to give a lower energy consumption than the incineration-only scenario, unless very high levels of incineration are used, where the energy savings from recycling are not sufficient to offset the reduction in energy produced from incineration (due to recycling).

For scenario 4, where material is collected via the dry recyclables scheme, the amount of paper/card recycled is slightly higher than for scenario 3. Because of losses during the sorting process the manufacturing energy is, however, somewhat higher than with scenario 3. Hence, the energy consumption associated with the paper/card waste chain/cycle for scenario 4 is higher. In addition the energy produced from incineration is lower because the amount of residual waste is lower, since more material is recycled: not only paper/card, but also plastic bottles/containers and metal cans, which are also collected by the dry recyclables scheme. This is slightly offset, however, by the fact that the calorific value of the refuse increases slightly with recycling via the dry recyclables scheme. Despite this, the overall effect is to cause the decrease in energy consumption (due to recycling) to be diminished as the level of incineration is increased until, above a level of ~ 80 %, the energy consumption becomes greater than for the scenario with incineration only.

Hence, a combination of recycling plus incineration of the residual waste would generally be the best waste management option, unless high levels of incineration (of the residual waste stream) were incorporated as part of the waste management strategy.

PLASTICS WASTE FRACTION

Collection Method

Comparison of the total energy consumption for the two different collection methods examined for the plastics fraction is shown in Figure viii. For each scenario recycling is only via the specified collection method. For instance, for the Dry Recyclables kerbside collection method the amount of material recycled via the plastics banks has been set to zero.

The graphs show that collection of the plastics fraction via the dry recyclables kerbside collection scheme consumes less energy than recycling via the plastics banks (17 % less at maximum recovery). The main reason for this is because the collection-miles for the kerbside scheme (~ 2 miles per tonne at maximum levels of recycling, although this is variable due to variable total transfer distance) are much lower than the transfer-miles required to transfer the plastics from the households to the WTS via the plastics banks (~ 570 total miles per tonne; i.e. sum of miles via bring-sites and via HWRC).

There are, however, sorting losses associated with the plastics collected via the kerbside scheme. In fact, losses are encountered twice: at the MRF, which separates the plastics from the other material; and at the plastics sort MRF, which separates out the different types of plastics. But the plastics collected via the banks are also sent to the plastics sort MRF so losses (although less) are also associated with this collection method. Thus, there will be less recycled plastics sent to the processing plant for collection via the kerbside scheme, resulting in a higher energy consumption associated with processing of the plastics. The difference in processing energy consumption is, however, not enough to offset the higher transfer energy consumption associated with collection via the plastics banks.

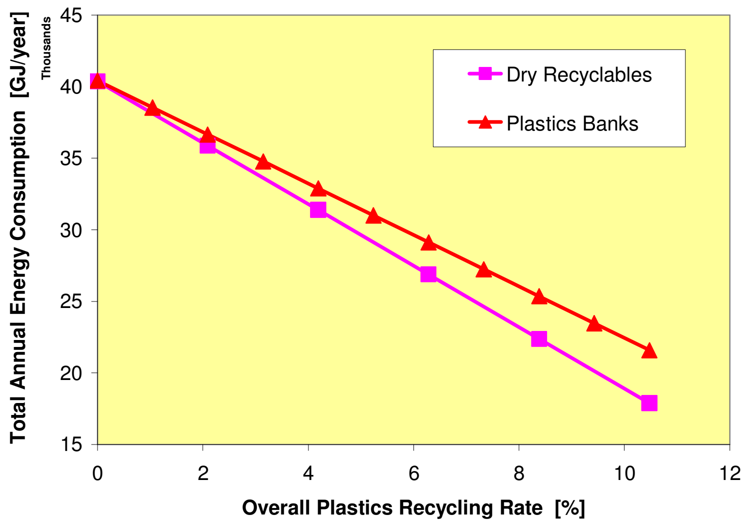

Figure viii: Effect of Recycling Method on Energy Consumption (Plastics Fraction)

The energy savings (compared to the base-case scenario) with maximum recycling are 45.5 % for recycling via the banks, compared to 54.9 % for recycling via the dry recyclables scheme.

Recycling versus Incineration

As with other waste fractions, the model for the plastics fraction also includes the option to incinerate rather than landfilling the residual waste stream. The effect that incineration has on the total energy consumption has been examined by comparing the base-case scenario with the following other scenarios:

1) recycling of the plastics via plastics banks with variable recovery rate, and landfill of the residual waste stream
2) no recycling of the plastics, and variation of the level of incineration of the residual waste stream (with landfill of the remainder)
3) recycling via the plastics banks with a 100 % recovery rate and variable levels of incineration
4) recycling via the dry recyclables scheme (100 % recovery rate) and variable levels of incineration

Firstly, the results show (Figure ix) that, compared to recycling with landfill of the residual waste stream, incineration without recycling gives a much higher maximum reduction in energy consumption. Secondly, the combination of recycling via plastics banks and incineration (scenario 3) gives a lower energy consumption than just incineration (scenario 2). This is because of the savings in energy consumption associated with recycling, which adds to the reduction in the total energy consumption.

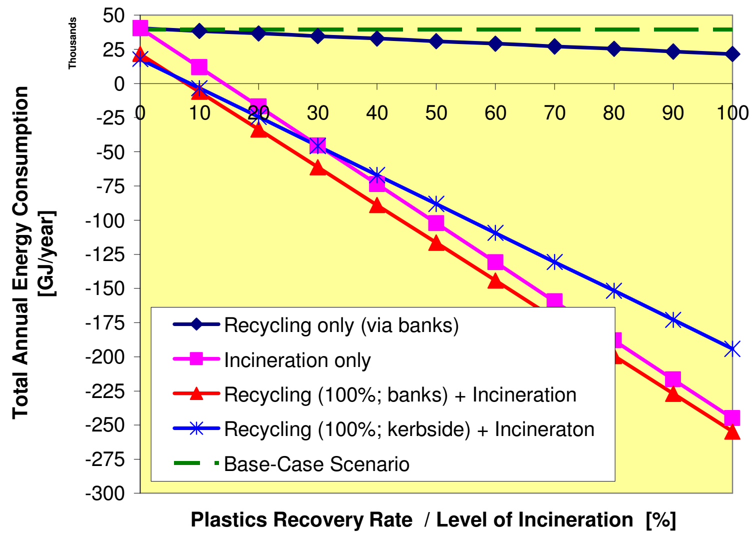

Figure ix: Comparison of Recycling and Incineration (Plastics Fraction)

With recycling via the dry recyclables scheme plus incineration (scenario 4) there is a cross-over point at ~30 % incineration level, however, where the energy consumption is higher than with incineration alone. This is because, as with the paper/card fraction, recycling via the kerbside scheme significantly reduces the amount of residual waste available for incineration. Thus, the amount of energy produced from incineration in this case will be lower than with incineration alone. This is because the fixed decrease, due to recycling, in the energy ***consumption*** for the production of the plastics (when compared to scenario 2) is offset by the decrease in the energy ***production*** from incineration. This offset becomes more dominant as the level of incineration is increased, thus causing the cross-over from less to more energy consumption, when compared to scenario 2.

METALS WASTE FRACTION

Recycling versus Incineration

To assess whether recycling of the metals waste fraction is better in terms of energy consumption than incineration, the following scenarios have been compared with the base-case scenario:

1) recycling of the metal cans via mixed metal cans banks with variable recovery rate, and landfill of the residual waste stream
2) no recycling of the metal cans, and variation of the level of incineration of the residual waste stream (with landfill of the remainder)
3) recycling via the metal cans banks with a 100 % recovery rate and variable levels of incineration
4) recycling via the dry recyclables scheme (100 % recovery rate) and variable levels of incineration

As with the other waste fractions the results show (Figure x) that, compared to recycling with landfill of the residual waste stream, incineration without recycling gives a much higher maximum reduction in energy consumption. Secondly, the combination of recycling via metal cans banks and incineration (scenario 3) gives a lower energy consumption than just incineration (scenario 2). This is because of the savings in energy consumption associated with recycling, which further reduces the total energy consumption.

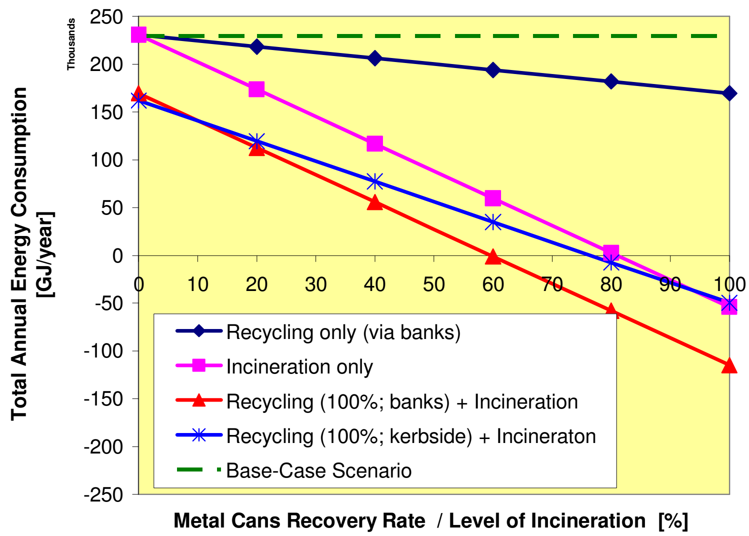

Figure x: Comparison of Recycling and Incineration (Metals Fraction)

With recycling via the dry recyclables scheme plus incineration (scenario 4) the difference between this scenario and the incineration-only scenario becomes less as the level of incineration is increased. Indeed, at a level of ~ 95 % there is a cross-over point where the energy consumption is higher than with incineration alone, although only slightly. This is because recycling via the kerbside scheme significantly reduces the amount of residual waste available for incineration. Thus, the amount of energy produced from incineration in this case will be lower than with incineration alone. This is because the fixed decrease, due to recycling, in the energy consumption for the processing/manufacture of the metals (when compared to scenario 2) is offset by the decrease in the energy production from incineration. This offset becomes more dominant as the level of incineration is increased, thus causing the cross-over from less to more energy consumption, when compared to scenario 2.

ORGANICS WASTE FRACTION

Centralised or Home Composting

Figure xi looks at the progressive replacement of a kerbside garden waste collection scheme (centralised composting) with composting at home. The scenario assumes that the recovery rates of material from the garden waste kerbside scheme and home composting (which also includes recycling of the kitchen compostable material) are the same. Then, the proportion of the population covered by the kerbside scheme is varied. Also, the amount of material collected via the HWRC site has been set to zero throughout.

The results show that, for a fixed recovery rate, the energy consumption decreases as the kerbside coverage decreases, since more material is progressively being diverted from kerbside collection. Also, below a kerbside coverage of ~ 20 %, the energy consumption decreases as the recovery rate is increased. Here, sufficient material is being diverted for home composting to offset the energy consumption required to transfer and process the material collected from the kerbside scheme.

Above ~ 40 % coverage, however, the energy consumption increases as the recovery rate is increased. Here, the amount of material diverted is not sufficient to offset the energy consumption associated with the recycling via the kerbside scheme. And, finally, between ~ 20 – 40 % coverage there is a transition period where the energy consumption switches from decreasing to increasing as the recovery rate is increased, simply because there is a point where there is a balance in the energy savings through diversion for home composting and energy consumed from recycling via the kerbside (when compared to zero recovery rate).

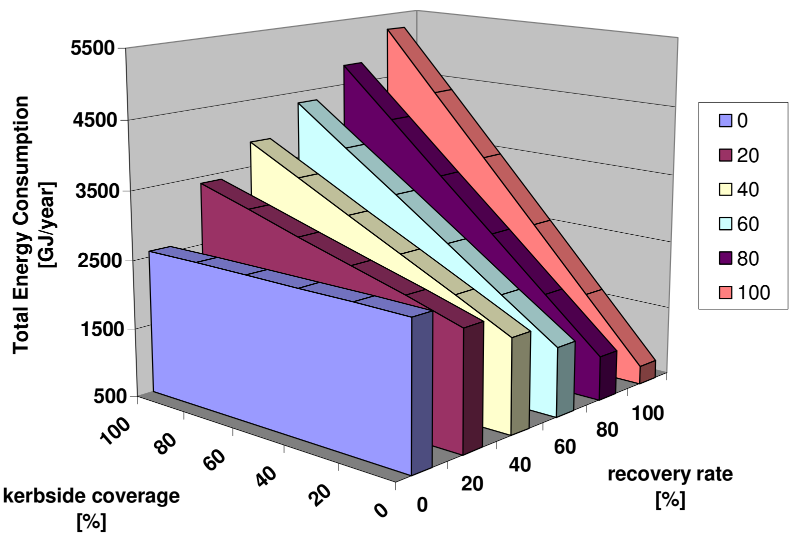

Figure xi: Replacement of Recycling via the Kerbside Garden Waste Scheme with Home Composting

The increase in energy consumption at maximum recycling of garden waste via kerbside collection is ~ 9 % when compared to the base-case scenario. Conversely, there are energy savings of ~ 84 % at maximum levels of home composting.

Recycling versus Incineration

The effect that incineration has on the total energy consumption has been examined by comparing the base-case scenario with the following other scenarios:

1) recycling of the garden waste via the HWRC site with variable recovery rate, and landfill of the residual waste stream
2) no recycling of the garden waste, and variation of the level of incineration of the residual waste stream (with landfill of the remainder)
3) recycling of the garden waste via the HWRC site with a 100 % recovery rate and variable levels of incineration
4) recycling via the garden waste kerbside scheme (100 % recovery rate) and variable levels of incineration

Firstly, the results show (Figure xii) that whilst recycling of the garden waste with landfill of the residual waste stream leads to an increase in the total energy consumption, incineration without recycling gives a large reduction in energy consumption. In addition, the combination of recycling, both via the HWRC site and the kerbside scheme, together with incineration of the residual waste stream (scenarios 3 and 4) gives a higher energy consumption than incineration of the residual waste stream alone (scenario 2). This is because, firstly, recycling increases the energy consumption associated with the recycling components of the waste chain/cycle. Also, recycling reduces the amount of material that is sent for incineration, resulting in a lower amount of energy produced from incineration.

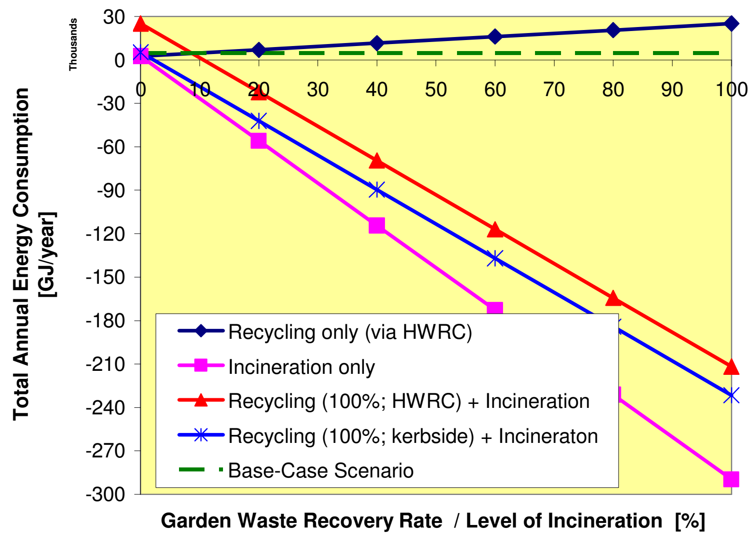

Figure xii: Comparison of Recycling and Incineration (Organics Fraction)

It should be noted that only composting of the organics fractions has been examined using the energy footprint model developed during the course of phase one of this project. Phase two, to be carried out as part of the EPSRC Sustainable Urban Environment Waste Consortium Programme, will further develop the model to include such technologies as Anaerobic Digestion (AD). Since this is an energy yielding process, it will be interesting to see if the trends found above will be different when AD of the organic waste fraction is considered.

GLOBAL WASTE MANAGEMENT

In previous sections the energy consumption for the management of the five main waste fractions was determined in isolation for various scenarios. Here, recycling of all five waste fractions collectively is considered for various scenarios (Figure xiii). For the scenarios shown recycling of the different waste fractions is generally as described for the individual materials, but with some slight changes, and is as follows:

- **Glass**: recycling is via bottle banks located at bring-sites and the HWRC with variable recovery rate.
- **Paper/card**: the amount of material recycled via the paper/card banks is kept fixed at the base-case scenario level; the recovery rate of the newspaper and magazines sub-categories only is then varied through recycling via the PaperChain scheme. At zero recovery rate the amount of material for all the paper/card sub-categories is set to zero.
- **Plastics**: recycling is via plastics banks located at bring-sites and the HWRC, with variable recovery rate.

- **Metals**: recycling of the metal cans only is varied, through changes in the recovery rate of these via mixed metal cans banks. The amount of material recycled for the other sub-categories of metal is kept fixed at the base-case scenario level.
- **Organics**: recycling only of the garden waste sub-category is varied. The amount of other sub-categories of the organics waste fraction is kept fixed at the base-case level. In addition, the amount of material recycled via the kerbside garden waste scheme is also kept fixed at the base-case level, and the recovery rate via the HWRC site then varied. At zero recovery rate the amount of garden waste collected via the kerbside scheme is also set to zero. Conversely, at 100 % recovery rate, the recovery rate for the material via the kerbside scheme is set to 100 % in order to give an overall recovery rate of 100 % for the garden waste sub-category.

Recycling of the five waste fractions is then varied collectively, with the amount of material recycled being varied accordingly in order to give the same recovery rate for each waste fraction. Hence, the scenario looks at an 'across-the-board' variation in the recovery rate of glass, newspapers and magazines, plastic bottles/containers, metal cans, and garden waste. The energy consumption associated with the recycling and processing/manufacture of each waste fraction is then determined, and summed to give a total for this. The energy consumption for the disposal of the residual waste stream (all waste fractions) is then added to this value in order to give the total ‘global’ energy consumption, and show the effect that recycling has on this. The global energy consumption for the following four different scenarios are considered, and compared to the base-case scenario:

1) Recycling only (as described above), with landfill of the residual waste stream
2) No recycling of the waste materials detailed above, and variable levels of incineration of the residual waste fraction, with landfill of the remainder
3) Recycling at the base-case levels, with variable levels of incineration of the residual waste fraction
4) Recycling with maximum recovery of the waste materials detailed above, coupled with variable levels of incineration of the residual waste fraction

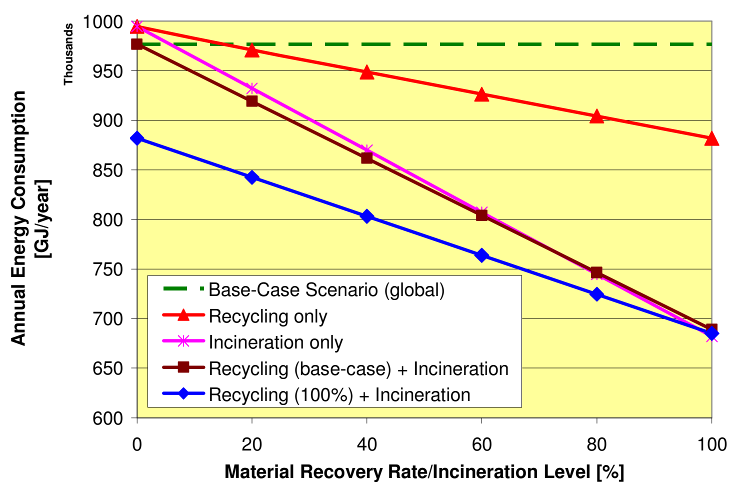

Figure xiii: Energy Consumption for Global Waste Management Options

The graph shows similar trends as found for the individual waste fractions. For recycling only there are total energy savings of ~ 9.6 % at the maximum recovery rate, when compared to the base-case scenario. As before, the energy consumption with incineration-only is significantly lower than the scenario with recycling-only, and there are savings of 30 % compared to the base-case scenario, and ~ 22.6 % when compared to the recycling scenario at maximum recovery.

The energy consumption for scenario 3 (base-case recycling plus incineration) is somewhat lower than scenario 2 (incineration-only) for levels of incineration less than approximately 60 %. At about 70 % there is, however, a cross-over point where the energy consumption becomes slightly more for scenario 3. The reason is as before (for the individual waste fractions): at low levels of incineration the savings in energy consumption through recycling are dominant; conversely, at high levels of incineration these savings are offset by a decrease in the amount of energy produced through incineration due to a reduction in the amount of residual waste available for incineration.

With maximum recycling combined with incineration of the residual waste stream (scenario 4), the energy consumption is lower (than scenario 2) for all levels of incineration, although there is convergence as the level of incineration is increased. Again, the reasons are the same: dominance of the energy savings made through recycling, that are progressively diminished as the level of incineration is increased.

The results suggest that if high levels of incineration are employed as part of the waste management strategy for Southampton, then in order to achieve minimum energy consumption it would not be necessary to recycle any of the materials detailed here. Conversely, at lower levels of incineration then it is better to recycle as much as possible in order to minimise the global energy consumption.

It should, however, be noted that there might be other scenarios that would give a lower global energy consumption: for example, maximum recycling of one waste fraction, but no recycling of another waste fraction. This will be examined in phase two of the project.

ENERGY FACTORS

It is difficult to compare the effects of recycling on the total energy consumption for the management of the different waste fractions, since the magnitude can be very different. For instance, the total energy consumption associated with the paper/card fraction for the base-case scenario is approximately 641,000 GJ/year, whereas it is only approximately 4800 GJ/year for the organics fraction. Therefore, the data has been expressed here in terms of an Energy Factor ("E-Factor"). This is the ratio of the energy consumption at a given recovery rate (or other parameter, e.g. level of incineration of the residual waste stream) to the energy consumption for the base-case scenario. Hence, the base-case scenario has an E-Factor of ONE, with a value below this indicating a decrease in energy consumption, and a value above indicating an increase (when compared to the base-case scenario).

The results in Figure xiv show that for all waste fractions except organics the E-Factors are less than one for recovery rates greater than the base-case level. For organics the E-Factor shows, however, that there is a five-fold increase in energy consumption at maximum recovery (of the garden waste fraction).

For the other waste fractions it can be seen that the E-Factors for glass and paper/card are not reduced much by recycling: ~ 6.6 % and ~ 5.1 %**,** respectively, at maximum recovery (of glass and newspapers/magazines, respectively). In contrast, the E-Factors for the plastics and metals fractions show significant reduction: by ~ 45.5 % for the plastics (maximum recovery of bottles/containers), and ~ 26.2 % for the metals (maximum recovery of metal cans).

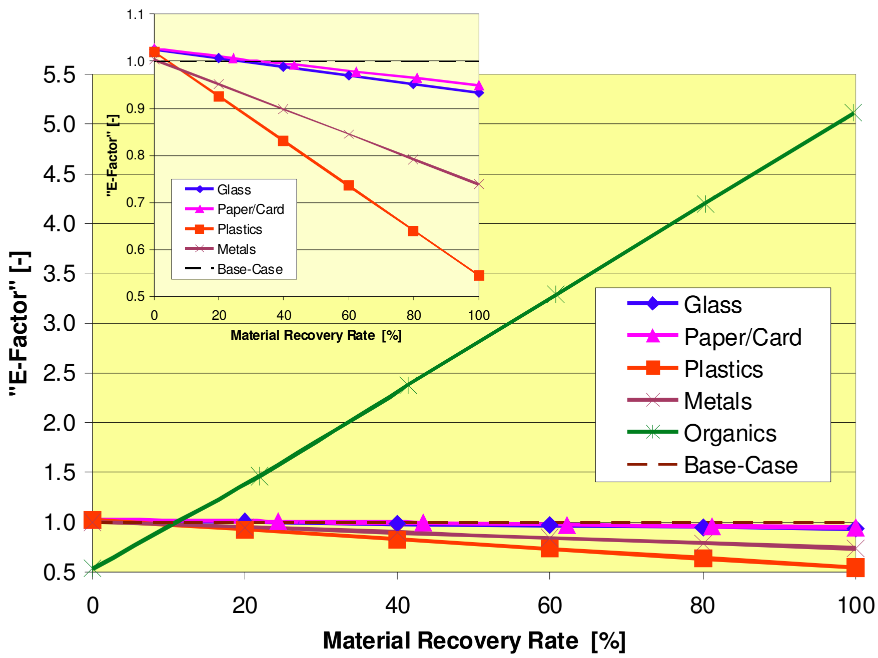

Figure xiv: Waste Fraction Energy Factors

ENERGY SAVINGS

Although use of the E-factors allows comparison of the savings made through recycling of the different waste fractions, it does not give an indication of the absolute savings made. These are shown in Table ii, together with the savings/increases per tonne material recycled. The results are for recycling via the collection methods as specified in the 'Global Waste Management' section above.

Savings/Increases:	Glass	Paper & card	Plastics	Metals	Organics	TOTAL
GJ/year absolute	4000	32879	18015	60096	-19863	95125
GJ/tonne recycled	1.03	4.18	15.45	28.53	-1.76	3.62
MWh electricity	336	2758	1511	5041	-1666	7980
no. of households	102	836	458	1528	-505	2418
no. of households (UK)	26778	220106	120600	402309	-132972	636808

Table ii: Energy Savings for Different Waste Fractions

The Table shows that, for instance, although the reduction in the E-Factor with recycling for the paper/card fraction is small, the absolute savings in energy consumption are relatively large (~ 33,000 GJ/year) when compared to the other waste fractions. For plastics, the reduction in the E-Factor with recycling is relatively large but, conversely, the absolute energy savings are relatively small. For metals, both the reduction in the E-Factor and the savings in energy are relatively large. These trends in absolute energy savings are also borne out by the savings per tonne of material recycled, expressed in terms of savings per additional tonne of material recycled, compared to the amount of material recycled for the base-case scenario.

Also given in the Table are details of the savings expressed in two other forms: the amount of electricity that can be generated from the absolute energy savings per year; and the number of households that can be powered by this electricity. The energy savings have been converted to the amount of electricity generated using the average conversion efficiency for electricity generation in the United Kingdom. The number of households within Southampton that this generated electricity will provide power for is then determined using an average annual household electricity consumption of 3300kWh. This can then be scaled up to give the savings that can be made across the UK, in terms of numbers of households.

The results show a wide variation in the number of households that can be powered from savings made through recycling of the different waste fractions: more than 400,000 households from metals recycling, compared to only ~ 27,000 from glass recycling. In contrast, since increased recycling of garden waste gives rise to an increase in energy consumption, there is a negative impact on the number of households that can be powered. Essentially, additional electricity must be generated that can be used to provide electricity for ~ 133,000 households across the UK.

If maximum recycling of all of the five main waste fractions indicated here was undertaken across the UK, then the energy savings would be sufficient to provide electricity for more than 635,000 households. This is equivalent to approximately 1.5 million people, more than the entire population (~1.25 million) of the county of Hampshire.

The results presented here represent the findings from the first (development) phase of the energy footprint project. The second phase will be carried out as part of the EPSRC funded Sustainable Urban Environment Consortium Programme ‘Strategies and Technologies for Sustainable Urban Waste Management’. This stage of the project will consist of three main components: additional data collection and development of approaches for problem areas; extension, updating and testing of the model in the light of incoming information; running of more advanced and sophisticated what-if scenarios; and development of a user-friendly interface to allow full utilisation as a research and planning tool.

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1 INTRODUCTION

The EU Landfill Directive and national strategy documents have set ambitious targets and deadlines for diversion and recycling: more broadly, prudent use of energy and raw materials is fundamental to sustainable development and will require a step-change in resource productivity. Progress in waste management is hampered, however, by the lack of methods to identify and promote sustainable practices. In the absence of such methods, choice is often driven by regulatory, financial or promotional reasons. There is thus an urgent need to develop tools for rational evaluation and comparison of alternatives for the collection, separation and processing of waste fractions. These tools must have a sound conceptual base, and allow comparisons at each stage in the waste cycle.

One of the best ways to assess sustainability is in terms of energy and materials balances, which can also be further related to outputs of Carbon Dioxide. Such an approach also allows consideration of the economics of sustainability, as it takes into account whole-life energy and materials inputs associated with each recovery/disposal option.

This report details an 18 month project set up under the UK's Landfill Tax Credit Scheme, with primary funding from Biffaward, and additional funding from the BOC Foundation, Hampshire County Council, Onyx Environmental, and Southampton City Council. The objectives of the project were:

- to understand, quantify and model energy usage associated with the collection, separation, processing and disposal of municipal solid waste (MSW).
- to produce an energy and materials balance that can be used for evaluation and comparison of different alternatives and combinations of options for MSW management.

A considerable amount of information is now available on waste quantities, material flows and mass balances, life cycle analyses and whole-life costings for the materials that constitute MSW. Data from these sources have been combined with information on the energy requirements for different types of collection and processing systems for re-use, recycling, recovery and disposal, and on the energy benefits from these options. The resulting model shows the energy footprint of current waste management practices, both individually and in combination, and allows exploration of alternative choices and combination of options. The project builds on existing studies, and highlights areas where insufficient information is available. The results indicate key areas where improvements in collection or processing technologies could have a significant impact on the final energy balance, and provides a rational basis for reduction in the amount of materials sent to landfill. The work is based on Southampton on the UK, but the methods and findings can be applied to other areas by modifying the input data.

Recent figures [1] indicate that the vast majority (~90%) of Southampton's household MSW is landfilled, with only ~8.5% recycled and the remainder (~ 1.5%) composted. With the imposition of the Landfill Directive, it is becoming increasingly more necessary to find other options for waste management. It is the aim of the model described in this report to address this need, and it focuses on all aspects of wastes management. For instance, with the glass fraction it not only looks at the production of cullet from recycled glass, and use of this cullet in glass manufacture, but also how the glass is transferred from the household to the glass processing plant, and from there to the glass furnace. In addition, it looks at options for the disposal of the non-recycled glass that remains within the residual waste stream (refuse). It also looks at different options for the transfer of the recycled glass from point A to point B, and alternative options for use of recycled glass.

Figure 1 shows a simplified diagram of the options for MSW management. On the left is the historical waste disposal route, where the MSW is predominantly 'disposed' of through incineration and/or landfill. Whereas landfill may be considered, to some extent, to be a one-way disposal process, incineration is somewhat cyclical in nature: MSW can be used as an energy source to produce electricity to power homes, and as district heating. There are, however, exceptions in both cases: landfill gas can be harnessed in order to produce electricity; and incinerators can operate as a means of waste volume reduction only, without electricity or heat generation.

Although the route on the left is the more traditional route, it is considered to be the least favourable, whereas recycling (and re-use) is the preferred waste management option (after waste minimisation). This route is indicated on the right of the diagram, using glass as an example.

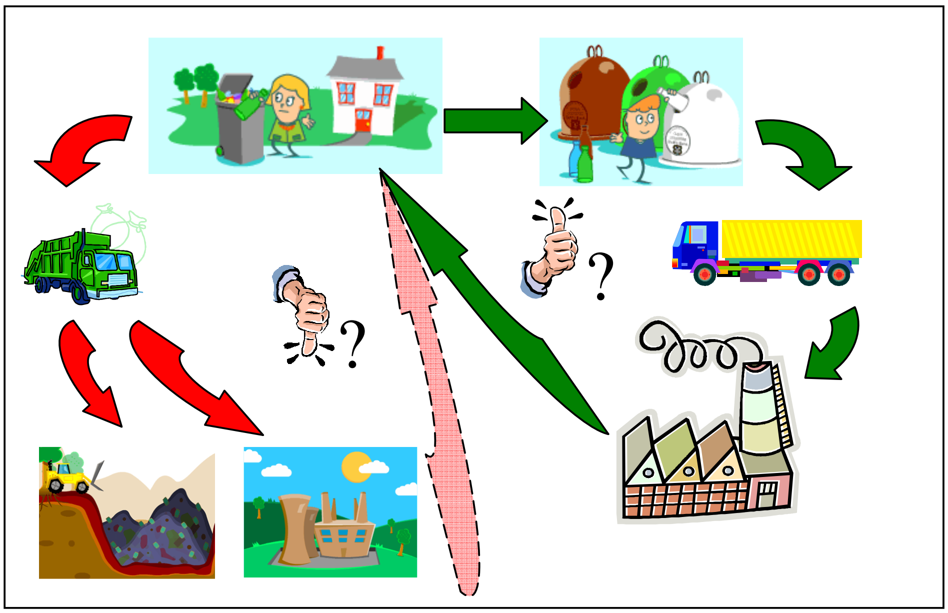


Figure 1.1: Simplified diagram of MSW Management [1]

Despite the fact that recycling enhances sustainability with regard to raw materials, does it also promote sustainable energy practices? There is an inherent energy consumption associated not only with the processing of the recycled materials, but also transporting the materials from point A to point B. Is this consumption of energy enough to offset any positive benefits from the use of recycled material in manufacturing processes? And, which is more important: savings in energy or conservation of resources?

The model (compiled in Microsoft Excel and Visual Basic) allows for various scenarios to be run, so that comparison can be made with the present-day situation, highlighting possible options for improvement of the management system for the different waste fractions.

[1] with acknowledgement to Rockware Glass for allowing use of images taken from the 'GLASSFOREVER' website

The Energy Footprint Model presently focuses on the management of the five main waste fractions: Glass, Paper/Card, Plastics, Metals, and Organics. Together, these materials constitute ~78 % of the household waste generated (83 % of the main categories, excluding 'miscellaneous'), and ~89 % of the total material recycled. Details of the amount of these materials and the other waste fractions generated by households in Southampton are summarised in Tables 1.1 and 1.2. The amounts of all the main waste categories generated and recycled are shown in Table 1.1, which indicates that there is an overall recycling rate of approximately 10.6 % for all household waste generated.

Waste Category	amount generated [tonnes/yr]	wt %	amount recycled [tonnes/yr]	recycling rate [%]
Paper & card	23562	26.02	4265	18.1
Plastic Film	6658	7.35	0	0.0
Dense Plastic	4981	5.50	53	1.1
Textiles	4538	5.01	213	4.7
Misc. Combustibles	5370	5.93	142	2.6
Misc. non-Comb.	1707	1.89	729	42.7
Glass	5326	5.88	1376	25.8
Ferrous Metals	3792	4.19	1047	27.6
Non-ferrous metals	876	0.97	49	5.6
putrescibles	24187	26.71	1543	6.4
fines	3235	3.57	0	0.0
Sub-Total	**84232**	**93.01**	**9417**	**11.2**
Miscellaneous	6335	6.99	177	2.8
TOTALS:	**90567**	**100.00**	**9594**	**10.6**

Table 1.1: Household Waste in Southampton (base-case scenario)

Table 1.2 shows the amounts generated and recycled of the five main waste fractions examined in detail in this study. The 'plastics' fraction combines the plastic film and dense plastic categories given in Table 1.1, whilst the 'metals' fraction combines the ferrous and non-ferrous metals categories. In addition, the 'organics' fraction represents the putrescibles category plus the wood sub-category of the miscellaneous combustible waste category.

Waste Fraction	amount generated [tonnes/yr]	wt %	amount recycled [tonnes/yr]	recycling rate [%]
Glass	5326	5.88	1376	25.8
Paper & card	23562	26.02	4266	18.1
Plastics	11638	12.85	53	0.5
Metals	4669	5.16	1095	23.5
Organics	25001	27.61	1680	6.7
TOTAL	**70196**	**77.52**	**8471**	**12.1**

Table 1.2: Household Waste Generated and Recycled: Main Waste Fractions (base-case scenario)

The model presented here represents the first (development) phase of the energy footprint project. The second phase will be carried out as part of the EPSRC funded Sustainable Urban Environment Consortium Programme 'Strategies and Technologies for Sustainable Urban Waste Management' ("SUE Waste Consortium"). This stage of the project will consist of three main components: additional data collection and development of approaches for problem areas; extension, updating and testing of the model in the light of incoming information from the other projects within the SUE Waste Consortium; running of more advanced and sophisticated what-if scenarios; and development of a user-friendly interface to allow full utilisation as a research and planning tool.

2 MODEL DESCRIPTION

The model adopts a linear modelling approach, and consists of individual, but inter-linked, sub-models associated with the various stages of waste disposal/processing. The majority of the sub-models are generic, i.e. independent of the type of waste material, with appropriate changes to the constants and variables used. Some of the sub-models are, however, material specific. Details of the sub-models for each of the waste materials examined are given in subsequent sections herein.

The model has been compiled in Visual Basic and is made up of the main programme, and a number of sub-programmes (Figure 2.1) incorporating the code for specific sub-models The sub-programmes are called from the main programme, and the total energy consumption is subsequently calculated by summation of the consumption for the specific components returned by the sub-models. The model has been validated by verification using independent calculations performed within Microsoft Excel spreadsheets. Supplementary notes to the Visual Basic code are given in Appendix A.

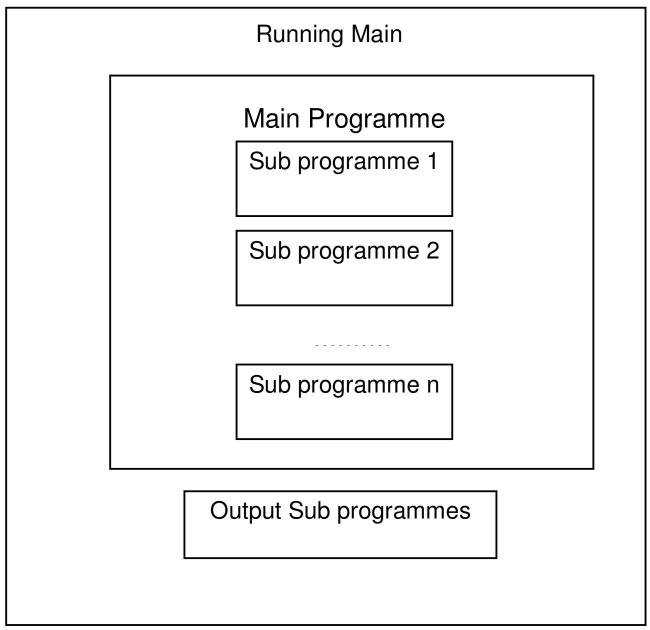


Figure 2.1: Structure of Visual Basic Model

The processes considered by the model start from the point where a particular material becomes waste and follows it through until disposal and/or processing. An example of the model processes is given in Figure 2.2, for the glass fraction, and also includes the system boundaries. Details of the processes and boundaries for the different individual waste fractions are given here in subsequent sections.

The model uses, where possible, actual figures of waste generation and material recycling within Southampton. The figures quoted in this report are, generally, average values for the period 2000 – 2002. These values have been used to populate the model because of the relatively good availability of data for this period; it would be difficult to get complete data for a period closer to the present-day. Hence, for the purposes of the model the “present-day” refers to the period 2000 – 2002. Henceforth, present-day will be referred to as “base-case scenario". When data becomes available for later years, this can be inputted in to the model to allow comparison with this base-case scenario.

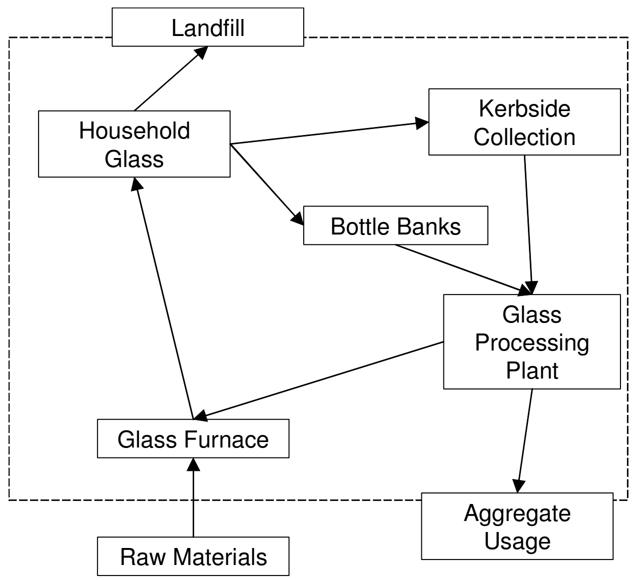


Figure 2.2: Model Processes and System Boundaries (Glass Example)

Details of the waste generated, material recycled, and refuse composition for the base-case scenario are given in Tables B1 – B5 in the Appendix, and have been summarised in Tables 1.1, 1.2. This is discussed in greater detail in section 2.1**.** The amounts of the different wastes generated by the households in Southampton were determined from the amount of waste disposed of by the householders via the kerbside refuse collection, and the amount of material recycled via the recycling facilities located throughout the city and the kerbside collection schemes in operation. The amount of refuse for each sub-category of waste is determined from the composition of the refuse as detailed in Table B3, and this is discussed further in section 2.1.
Other parameters and values used in the model are also obtained from actual data, where possible, for the waste management infrastructure operating in Southampton. Where necessary, data has, however, been taken from the literature and other sources of information, although the model is continuously being updated with actual and/or more accurate data, as this data becomes available.

Before continuing it is pertinent to note here that the Energy Footprint model has been developed in stages. The initial stage was the development of the glass model, as described in section 2.2, followed by expansion and adaptation of this model to incorporate the other waste fractions. The model described in this report is, therefore, the product of several developmental stages since it was necessary to make significant changes to the initial glass model. This included, in particular, changes to the waste classification system used for the refuse composition, etc. The present version of the model is described here, but it should be noted that some of the publications, etc., published during the course of the project refer to earlier versions of the model, and show results obtained using these versions of the model.

2.1 REFUSE SUB-MODEL

In order to complete the 'waste' cycle, it is necessary to also take into account the material that is not recycled but remains within the general household residual waste stream (refuse). For this model the amount of material within the refuse for the base-case scenario has been estimated from compositional data [2] and actual monthly refuse tonnages [3]. The model presently uses a breakdown of the refuse into 11 categories, according to references [2, 4], and each category is further sub-divided into sub-categories that, generally, correspond to those given in to reference [2]. This sub-categorisation of certain components is necessary because of the complexity associated with the recycling of some materials.

One example is the paper/card fraction, for which there is currently a kerbside collection scheme in Southampton, collecting newspapers, magazines and leaflets (‘PaperChain’). These sub-categories (and to a lesser extent, office paper) are also recycled via paper banks, whereas cardboard and other card is generally recycled via the HWRC site. The proportion of each of these sub-categories within the refuse and for the different recycling methods (banks, kerbside) is fixed for the base-case scenario. If, however, the model only uses a classification of the eleven main categories, it will not account for this fact. For instance, setting a recycling rate of 100 % (of the Paper/Card category) for recycling via the PaperChain scheme would mean that ~ 23,562 tonnes/yr (Table B1) of Paper/Card would theoretically be collected. The scheme, however, only collects newspapers/magazines, and there are only ~11, 704 tonnes of these available on total. Therefore, it is necessary to sub-categorise paper/card in order to account for this, thus allowing the model to independently vary the recycling rate for these different sub-categories. Without this, it would also not be possible to accurately account for recycling via different methods.

Details of the composition of the residual waste stream (refuse) are given in Table 2.1, which shows the composition and properties for the main waste categories. Appendix B gives details of the full waste classification (Table B3), together with the overall (Table B4) and individual (Table B5) properties of the different waste sub-categories. Table B3 shows the composition (on a weight-basis) and amount of the material that leaves the households of Southampton and is collected by the weekly refuse collection. The composition is based on the study by [2] and the amount of material collected (kg per household per week) is based on this composition and the total amount of refuse generated annually within Southampton (see below) [3].

Category	Composition [wt%]	Amount kg/hh/week	Moisture content [wt%]	net CV [MJ/kg]	Ash content [wt %]
Paper & card	25.79	4.04	1.82	4.31	1.00
Plastic Film	8.90	1.39	0.02	3.69	0.09
Dense Plastic	6.59	1.03	0.01	2.47	0.04
Textiles	5.78	0.91	0.40	0.92	0.15
Misc. Combustibles	6.99	1.09	3.66	0.74	0.33
Misc. non-Combustibles	1.31	0.20	0.14	0.00	1.28
Glass	5.28	0.83	0.00	0.01	5.25
Ferrous Metals	3.67	0.57	0.00	0.02	1.26
Non-ferrous metals	1.11	0.17	0.00	0.00	1.01
Putrescibles	30.27	4.74	11.37	3.83	0.84
Fines	4.32	0.68	0.12	0.32	2.82
Totals	**100.00**	**15.66**	**17.53**	**16.31**	**14.05**

Table 2.1: Composition of Southampton’s Refuse

It can be seen from Table B3 that some of the sub-categories are specific to Southampton. For instance, the 'Textiles' category contains sub-categories for textiles from several different charity banks located in Southampton. These sub-categories have been included in the refuse in order to allow for increase/decrease in the recycling of this material. The amount of material in each sub-category is based on the current split of material between the different recycling schemes and the original amount of 'Natural & Man Made Fibres' as detailed in reference [2]. Therefore, the model allows for changes in the amount of material being recycled through individual schemes, which gives the model a greater degree of flexibility. For instance, if less material is recycled via the Salvation Army banks then this material (in the model) will go in to this sub-category of the refuse. Conversely, if more material is recycled via the Salvation Army banks, this will come from the corresponding sub-category in the refuse. This does, however, limit the maximum amount of material that can be recycled through any one charity and does not allow, for instance, a situation where the overall amount of textiles is recycled through an increase in recycling via one particular charity. In this instance it would be necessary for the model to take textiles in the refuse from other sub-categories (i.e. material "allocated" in the model for other charities). This issue, will however, be addressed in future developments of the model.
Similarly, other categories have been expanded to include extra sub-categories that represent specific sub-categories of material that are recycled via various schemes, or taken to the Endle St. HWRC site for disposal.
The moisture content and calorific values (CV) for each waste category given in Table 2.1 are the contribution that each category makes to the total value, i.e. the refuse as a whole. To obtain these values, the values for each individual waste (sub-) category is multiplied by the corresponding weight-percent for that category. For instance, the contribution of the newspapers (0.36%) to the moisture content of the refuse is calculated from the moisture content for newspapers (5.97 wt%) multiplied by the weight-percent of the newspapers in the refuse (5.98 %). Details of the contribution that each sub-category makes to the bulk (overall) moisture content, calorific value and ash content of the refuse are given in Table B4. Here, the net CV is given, which is the lower heating value of a substance. This is generally quoted/used when determining the heat generation during combustion (for heat/power generation purposes). The CV of a substance is, however, normally measured on a gross basis (higher heating value; i.e. the heat of vaporisation of the moisture in a substance is recovered during heat/power generation), and it is these values that are generally quoted in the literature. Hence, Table B5 gives the gross CV, as well as the moisture and ash content, for the different individual sub-categories. The net CV is then estimated by deducting the heat of vaporisation of the moisture from the gross CV.
The model has been designed such that if the recycling rate of any particular material is varied, then the amount of this material in the refuse will change and the model will take this into account and re-calculate the composition of the refuse. It will also automatically re-calculate the properties of the refuse (CV, etc.).

It should be noted that the waste composition presented here is estimated from the analysis of refuse samples taken in 1999, which was the most up-to-date and detailed compositional analysis available for Southampton at the time of the project. It is recognised that the composition is likely to have changed in the past few years, especially since the kerbside collection of paper was introduced after the study was undertaken. Therefore, the model will be updated as and when new, accurate, compositional data becomes available. Alternatively, the composition for the base-case scenario could be estimated by taking into account the average yearly tonnages of paper and garden waste collected via the kerbside schemes

(PaperChain and Green Waste Trial Scheme) introduced since 1999, and adjusting the composition given in Table 2.1 accordingly. The next stage of the Energy Footprint project, which will be undertaken as part of the SUE Waste Consortium Programme, will use this estimated updated composition.

The yearly refuse tonnage for the base-case scenario is estimated to be 74815.2 tonnes, which is an average for the period 2001-2002 [3]. This is for 91895 households [5], giving the weekly figure of 15.66 kg/hh/week, as indicated in Table 2.1. From this, the yearly tonnage of the different waste fractions present in the refuse can be determined. These values are summarised in Table 2.2, and given in full detail in Table B1. Also detailed in the Tables are the amounts of household waste generated and the amount recycled (excluding the "Miscellaneous"/"Additional" material, as shown in Tables 1.1 and B1). Here, the amount generated is simply the sum of the amount in the refuse and the amount recycled. In addition, for some types of waste, details are also given of sub-categories, etc. For instance, the different amounts of the wood sub-category for 'Misc. Combustible' waste is given since, for the purposes of the model, this has been added to the 'Putrescibles' category to form a larger 'Organics' waste fraction (25001.35 tonnes/yr generated; 23320.98 tonnes/yr to disposal; 1680.38 tonnes/yr recycled). This category forms one of the five main waste fractions examined in detail in this report. Another of the five waste fractions is 'Plastics', which in the refuse composition model has been split into two categories: Plastic Film and Dense Plastic.

Category/sub-category	Amount of Household Waste [tonnes/yr]	wt %	Amount to Disposal [tonnes/yr]	Amount Recycled [tonnes/yr]
Paper & card	**23561.95**	**26.02**	**19296.23**	**4265.72**
Plastics	**11638.43**	**12.85**	**11585.26**	**53.17**
Plastic Film	6657.76	7.35	6657.76	0.00
Dense Plastic	4980.67	5.50	4927.50	53.17
Textiles	**4538.35**	**5.01**	**4325.67**	**212.68**
Misc. Combustible	**5370.04**	**5.93**	**5228.41**	**141.63**
Wood	814.27	0.9	677.06	137.21
Misc. non-combustible	**1707.22**	**1.89**	**977.98**	**729.25**
Glass	**5325.62**	**5.88**	**3949.52**	**1376.10**
Ferrous metals	**3792.47**	**4.19**	**2745.86**	**1046.61**
Non-ferrous metals	**876.33**	**0.97**	**827.52**	**48.81**
Putrescibles	**24187.08**	**26.71**	**22643.92**	**1543.17**
Garden Waste	12865.12	14.21	11321.96	1543.17
Kitchen Compostable	7560.51	8.35	7560.51	0.00
Kitchen non-Compostable	3761.45	4.15	3761.45	0.00
Unclassified	0.00	0.00	0.00	0.00
Fines	**3234.85**	**3.57**	**3234.85**	**0.00**
Total:	**84232.35**	**93.01**	**74815.20**	**9417.15**

Table 2.2: Household Waste in Southampton (base-case scenario)

2.2 GLASS FRACTION

For the glass waste fraction the following sub-models are employed:

1. stage 1 transport (household to bottle bank)
2. stage 2 transport (bottle bank to processing plant)
3. kerbside collection
4. glass processing plant
5. cullet transfer
6. glass manufacture
7. refuse collection
8. landfill transfer
9. incineration

Essentially, these sub-models represent the flow of the glass waste from the household to the final destination, be it glass manufacture, landfill, incineration, or alternative uses. The flow of glass for recycling is from the household to the bottle bank (located at a bring-site or a Household Waste Recycling Centre, HWRC), then from the bottle bank to the processing plant, where the glass is crushed and, if required, sorted to produce so-called cullet. The cullet is then transported to a glass manufacturing plant, or elsewhere (for example, to be used as aggregate). The model also allows for the possibility of using a kerbside collection scheme (presently only source-segregated glass) for collection of glass for recycling.

The glass that is not recycled will remain within the residual waste stream (refuse) and be collected by refuse collection vehicles (RCVs) and taken for disposal at a landfill site, or incineration in an Energy from Waste (EfW) facility.

The model does not, however, presently take into account the mining, transportation, etc., of the raw materials used in glass manufacture, production of aggregates, or other materials that can be replaced by cullet. Also, it does not consider, in any great detail, the alternative uses of glass (e.g. as aggregates), other than to allow diversion away from use in glass manufacture.

In addition, the impact of waste minimisation or re-use is not considered because it is rather difficult to quantify these areas. The model could, however, be adapted to examine them, particularly if a (detailed and accurate) mass balance of households was included in the model. This would not only look at the waste leaving the household, but also material/goods production and input to the household.

Bottle Banks:
Clear Bottles & Jars
Green Bottles & Jars
Brown Bottles & Jars

Kerbside Scheme:
Clear Bottles & Jars
Green Bottles & Jars
Brown Bottles & Jars

Refuse Collection:
Clear Bottles & Jars
Green Bottles & Jars
Brown Bottles & Jars
Other Glass

Figure 2.3: Distribution of Glass Sub-Categories amongst Collection Systems

Details are given below of the different (sub-) categories of glass covered by the model (Table B1 in the Appendix). The figures in brackets refer to 1) the waste category/sub-category codes (e.g. 7.01); and 2) the proportion, by weight, that each sub-category contributes to the total amount of household glass. Here, "Other glass" generally refers to broken glass, including broken bottles/jars, plate glass and other such items. The distribution of each sub-category of glass amongst the various possible collection systems is shown in Figure 2.3, and the waste management structure for the disposal/recycling of glass is shown in Figure 2.4.

Glass (waste category 7):
Clear Bottles & Jars (7.01) (54.38 % of total household glass, by weight)
Green Bottles & Jars (7.02) (32.55 %)
Brown Bottles & Jars (7.03) (11.66 %)
Other Glass (7.04) (1.41 %)

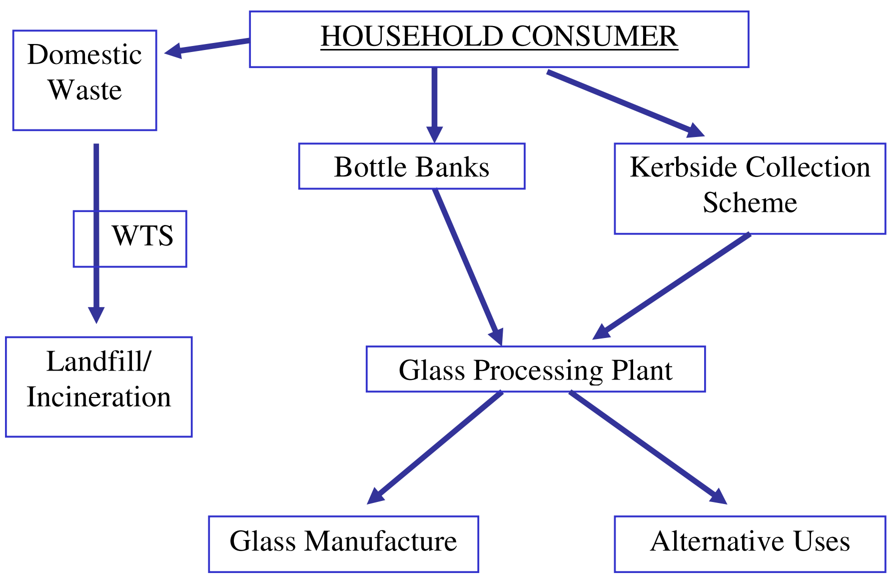


Figure 2.4: Glass Waste Management Scheme

2.2.1 Stage 1 Transport

The first sub-model, or stage 1 transport, considers the initial transfer of material from the household to the first step in the recycling chain/cycle. It only considers, however, those situations where material is taken by the inhabitants of a household to a recycling facility. It does not consider collection of material from the household, i.e. kerbside collection schemes, which are dealt with by a separate sub-model.

2.2.1.1 Bottle Bank at Bring-Site

This is the transfer of glass from the household to the bring-site, defined in this model as recycling centres that are located at places such as Supermarkets, Car Parks and Public Houses, rather than HWRCs, otherwise known as Civic Amenity (C.A) sites. The majority of glass recycling via bring-sites takes place either on foot or by car. Hence, other methods of transfer (public transport, bicycle, etc.) are not considered. Also, for the purposes of this

model, only transfer by car is considered, since human "energy consumption" is presently excluded from the model.
For transfer of material by car, the journey may be either incidental (e.g. recycling at a supermarket bring-site during a visit to do the weekly shopping), or specifically for recycling. Here, only the journeys undertaken specifically for recycling are considered, since the model is only concerned with the energy consumption directly attributable to the waste management process, whether it is disposal, processing, or recycling.

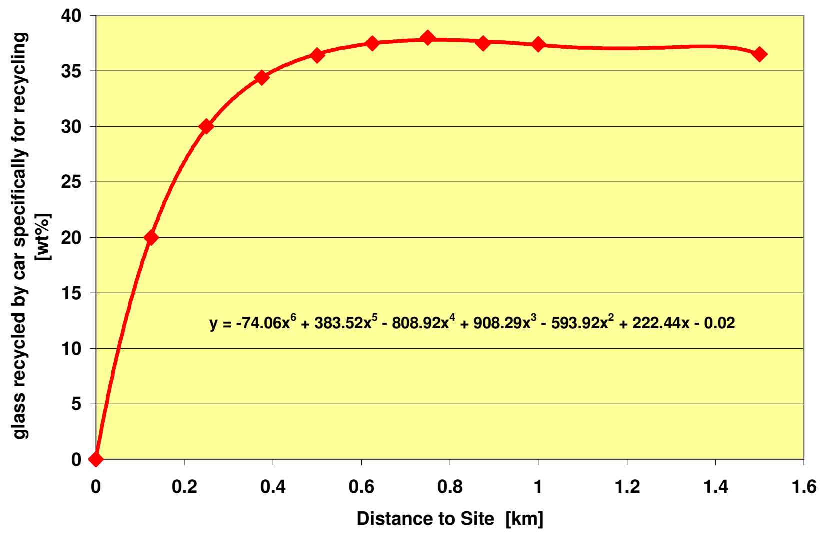


Figure 2.5: Material taken to Bring-Sites by Car as a function of Distance to Site

The percentage of journeys made specifically for recycling is dependent upon the average distance to the bring-site (Figure 2.5, adapted from [6]), and this distance, L, can be determined from the following equation [6]:

$$L = \frac{1}{2 \cdot \sqrt{\pi SP}} \; [miles] \qquad \textbf{(1)}$$

where, S is the site density (sites per inhabitant) and P is the population density (inhabitants per sq.km). For Southampton there are a total of 86 bottle banks located at bring sites (average number for the period 2000-2002 [7]), corresponding to a site density of 3.954 per 10,000 inhabitants. The population of Southampton was 217,478 in 2001 [8], and the area of the city is 19.24 sq.miles [9], giving a population density of approximately 11,300 inhabitants per sq.mile. Using equation (1) gives a value of L = 0.1335 miles (0.215 km), and from Figure 2.5 approximately 27.8% of trips are made by car specifically for recycling. The average return-journey trip is simply 2 x L, i.e. 0.267 miles.
The model allows for variation in the site density, which in turn automatically adjusts the percentage of trips made specifically for recycling (from Figure 2.5, using equation 1 to determine L; valid for distances up to ~ 1 mile), and calculates the average journey distance. Once the average distance to the bring sites has been determined, the overall yearly number of trips, BS_{tr}, is calculated, using the following equation:

$$BS_{tr} = \frac{BS_R \text{ x } T_R}{\left(M_{GC} / 1000 \right)} \qquad \textbf{(2)}$$

where,

BS_{tr} = no. of trips to bring-site per year

BS_R = tonnes of glass recycled via bring-sites per year (presently 1271 tonnes – average for the period 2000-2002)

T_R = percentage of trips made by car specifically for recycling (presently ~ 27.8 %)

M_{GC} = mass of glass taken to bring-site per car trip (assumed = 4.5 kg, [6])

This gives a rounded figure of 78523 trips per year, which is then multiplied by the average return-journey distance per trip to give an annual mileage of 20,965 miles for the present-day situation ("base-case scenario", which refers to the period 2000-2002).

It should be noted that the model currently assumes that only glass is taken to the bring site per trip. In reality, this will not be the case, and other recyclable material will normally be taken to a bring site together with the glass. This assumption will be addressed in future developments of the model.

In order to determine the energy consumption, the fuel consumption must first be determined. In this model the fuel consumption is calculated using the method given in [6], with data taken from [10], assuming that 50 % of the cars that are used to take the glass to the bring-site have catalytic converters and all are petrol driven. For conventional vehicles with engine capacities within the range 1.4 - 2.0 litres the fuel consumption, FC, is given by:

$$FC = 606.1v^{-0.667} \;\; [grams/km] \qquad \textbf{(3)}$$

where v is the average vehicle speed [km/hr]. For vehicles with closed loop catalysts and the same engine capacity the fuel consumption is given by:

$$FC = 106.43 - 1.862v^{-0.667} + 0.01562v^2 \; [g/km] \qquad \textbf{(4)}$$

The above correlations are valid for speeds between 10 and 60 km/h (~ 6 – 37 mph). Because most people do not travel very far to take their glass waste to bottle banks, there is generally not sufficient journey time to allow the engine to warm up. Hence, additional fuel is used due to a cold engine, and this must be accounted for in the calculations. The distance, L_{cold}, required to warm up the engine is estimated by:

$$L_{cold} = 4.0 - 0.06\vartheta \; [km] \qquad \textbf{(5)}$$

where ϑ is the ambient air temperature [^{o}C], which is assumed to be 10^{o}C for this model [6]**,** giving a cold trip length of 3.4 km (~ 2.1 miles). This exceeds the distance travelled by most people specifically for recycling purposes. Therefore, it is assumed that all car trips made specifically for recycling are undertaken with cold engines. Hence, a cold engine correction factor must be applied, which gives the fuel use ratio for cold to hot engines, δ_{fuel} [6]. For this model the correction factor is given by:

$$\delta_{fuel} = 1.47 - 0.009\vartheta \qquad \textbf{(6)}$$

An average speed of 30 km/hr (~18.6 mph) is used in this model, which is the average speed for urban driving conditions in the EU [10]. Applying the above equations and conversion factor gives an average fuel consumption of 141.4 g/mile. From this, the annual energy consumption for transporting the glass from the household to the bring-site can be calculated for a given site density and glass recycling rate. For the present situation in Southampton this gives an energy consumption per vehicle trip of approximately 1.73 MJ, corresponding to a total annual consumption of 136 GJ.

2.2.1.2 Bottle Bank at HWRC Site

Glass is not only recycled via bring-sites located strategically throughout the city, but also at bottle banks located at HWRC sites, where the amount of glass recycled can be significant. Indeed, for the base-case scenario the proportion of glass collected via one site, Endle Street, represents approximately 7.7 % of the total glass currently being recycled in Southampton.

To simplify the model only the HWRC site located at Endle Street is considered. Other sites could be considered but these are located in areas that also serve populations from other Councils/Districts. Likewise, there are sites situated in other Districts surrounding Southampton that are also visited by residents of Southampton, making it difficult to apportion the amount of use by residents of Southampton. This may be an area for future research, possibly in the second phase of the Energy Footprint project, within the SUE Waste Consortium Programme.

The calculations of the energy consumption for transport of glass from the household to the HWRC is similar to that for bring-sites. Indeed, the fuel consumption calculations are identical. The trip distance and some other parameters are, however, somewhat different. Firstly, since only one HWRC is considered, equation (1) is not applicable. Instead, the model presently assumes an estimated average distance to the site of 2.5 miles. This is based on data from a survey carried out at HWRC sites within Hampshire [11]. It should be noted that this distance (equivalent to 4 km) is greater than the cold trip length of 3.4 km. Since it is not, however, a significantly greater distance the model still assumes that the engine is cold and, hence, applies the same calculation methodologies as for transport to bring-sites. Furthermore, since the trip is a return journey, it is assumed that sufficient time is spent at the HWRC site to allow the engine to cool back down before the return journey is made. Also, it is assumed that 100% of trips to the HWRC are made by car and specifically for recycling. The validity of these assumptions will be examined further in phase two of the Energy Footprint project and, if necessary, changes will be made to the model.

In order to determine the amount of each material taken to the HWRC per trip, the model firstly assumes that each vehicle carries an average load of 20 kg. This is an estimate, and a more accurate value will be used in future developments of the model. It is then assumed that the amount of each material taken to the HWRC site per trip will be a fraction of this 20 kg, based on the percentage of each material found at the site. This is estimated from the monthly reports supplied by SCC [3] and EPA data from HCC [12], for the period April 2001 – January 2003.

Details of the breakdown of the materials taken to the HWRC are given in Table B6 in the Appendix. Not presently included in this breakdown are materials that go in to the 'General Waste' skip, or other materials such as waste oil (see Table B1). The management of these materials are presently not included in the model, but will be included in future developments. This does not, however, affect the present model since it will still allow comparative examination of different waste management options for the other waste materials.

For the base-case scenario for Southampton, 105.1 tonnes of glass per year are collected at the HWRC located at Endle Street in Southampton [3, 12]. As shown in Table B6, this represents approximately 2.9 % of the total material taken to the site, which is equivalent to 0.58 kg/vehicle.

Using the above methodology, the overall (total, for all materials) energy consumption per trip is calculated as 32.4 MJ for the base-case scenario. The number of trips per year is calculated in a similar manner as for the bring-sites, but using the total amount of material taken to the HWRC (Table B6), giving a total of 180,343 trips. In order to determine the annual energy consumption associated with the glass fraction, the total consumption value is multiplied by the proportion of glass taken to the site per trip (~2.9%), which gives an annual energy consumption of approximately 170 GJ (5845 GJ/year for all the materials).

2.2.2 Stage 2 Transport

The next stage in the recycling chain/cycle is the transfer of the glass from the bottle banks to the glass processing plant. The situation in Southampton is somewhat unique, in that a new processing plant at the Docks began operating at the beginning of 2003, and the majority of the cullet processed here will be transferred onwards by ship. Transfer of the bottle banks to the processing plant takes place by skip lorry, and the banks are emptied at the processing plant.

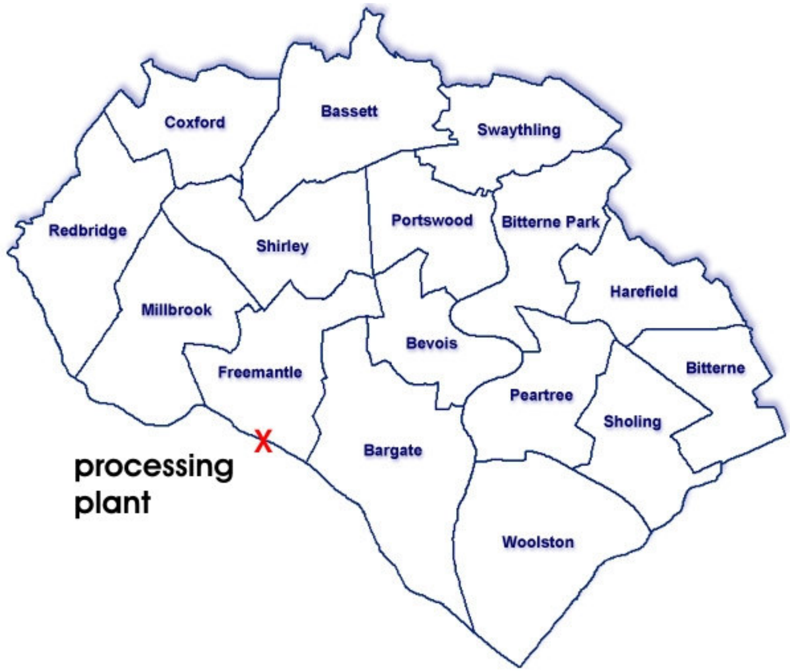
2.2.2.1 Bring-Site

For the bottle banks at the bring-sites the average distance to the processing plant is determined by use of a route planner to calculate the distance from the plant to several points at the outer boundary of Southampton (Table 2.3; Figure 2.6). It is then assumed that the average distance to the plant will be half of the average calculated distance. This gives a return-journey trip distance of 7.34 miles.

WARD	Road	Postcode	Distance to Processing Plant
Redbridge	Gover Road	SO16 9BR	3.34 miles
Coxford	Buchanan Road	SO16 8GN	5.18 miles
Bassett	Lingwood Close	SO16 7GB	6.96 miles
Bitterne Park	The Gregg School, Townhill Park House, Cutbush Lane	SO18 2GF	7.77 miles
Harefield	Minstead Avenue	SO18 5FW	8.74 miles
Bitterne	Kinsbourne Way	SO19 6BH	9.25 miles
Sholing	Daintree Close	SO19 0RX	8.52 miles
Woolston	Staplehurst Close	SO19 9QS	8.90 miles
Processing Plant	Herbert Walker Avenue	SO15 1HJ	-
	Average distance [miles]		7.33 miles
Average distance (mid-point) [miles]			3.67 miles

Table 2.3: Determination of Average Distance to Glass Processing Plant

For the loading and unloading of the bottle bank at the bring-site, it is assumed that each requires a time of five minutes. For emptying the bank at the processing plant, a time of ten minutes is used based on average times taken from weighbridge ticket data [3].
Fuel consumption figures have been taken from [6], assuming a truck size of 10 tonnes (max. net payload) for the skip lorry, with a figure of 15.9 MJ/km (~ 25.6 MJ/mile) being used for urban travel and a figure of 238 MJ/hr (23.8 MJ/km, at 10 km/hr) being used for the loading/unloading phase (equivalent to 79.3 MJ per bank). This gives an overall energy consumption of 267.2 MJ per bottle bank collection. The number of collections per year has been taken to be 348, which is an average figure for the actual number of collections made in Southampton in the period 2000 - 2003 [9], giving an annual energy consumption of approximately 93GJ.



(source: SCC - modified)

Figure 2.6: Map of Southampton's Wards and Boundary

2.2.2.2 HWRC Site

For the HWRC site the calculations methods are identical, but some of the constants are different. Firstly, the return journey distance is taken to be 5.52 miles, estimated using a route planner, with Endle Street as the start point and the processing plant as the end point. Also, the number of collections from the HWRC site is taken to be 36 per year, which is the average number for the period 2000 - 2003 [3]. This gives an energy consumption per collection of 220.6 MJ, which equates to an annual consumption of approximately 8 GJ.

It should be noted that the model assumes that the number of collections varies proportional to the amount of glass recycled: if the amount recycled is doubled, then the number of collections is also doubled. Also, the split between the amount of glass recycled via bring-sites and via the HWRC site is kept constant, independent of the amount of glass recycled. The values used for the base-case scenario are 92.36 % (1271 tonnes) via bring-sites and 7.64 % (105.1 tonnes) via the HWRC site. Future developments of the model will, however, allow independent variation of this split.

The stage 2 transport sub-model can also be varied to allow for "non-local" transfer of bottle banks to the processing plant at the Docks. For instance, the processing plant actually takes glass collected from throughout Hampshire and further afield. In this situation the bottle banks may not be transported to the Docks individually using a skip lorry because the distance is too far. Therefore, it is assumed that the bottle banks are emptied into a 10 tonne payload truck [6] until it is full, then transported to the processing plant. Using a 10 tonne payload truck will reduce the number of collections required, compared to using a skip lorry to transport one bottle bank per trip with, from above, an average load of approximately 3.6 tonnes. For example, for the base-case yearly tonnage from bring-sites of 1271 tonnes the number of collections would be approximately 127, compared to 348 for transfer by skip lorry.

Alternatively, the bottle banks could first be taken by skip lorry to a local Waste Transfer Station (WTS). From here the glass could then be transferred to the processing plant using a 10 tonne payload truck.

2.2.3 Kerbside Collection

The model also includes the option for the introduction of a kerbside collection scheme within Southampton. It is assumed that the scheme would operate on a fortnightly basis, given the relatively low amounts of glass in domestic refuse.

The model assumes that a 10 tonne capacity truck is used for the kerbside collection scheme, and the number of collections and collection round distance is calculated in the same manner as for the refuse collection. If the number of collections are less than one per fortnight, then the maximum distance of approximately 355 miles (571 km; [13]) is used (for 100 % coverage of the city); otherwise, the distance travelled is dependent upon the amount of material collected per fortnight. The model also allows for the option to have a partial introduction of the kerbside scheme, covering only part of the population of the city. For this scenario, it is assumed that those covered by the scheme are all located in the same particular area of the city. Hence, the distance travelled is adjusted accordingly. For example, if 50 % of the population have the kerbside scheme then the maximum collection distance is half of 355 miles. As with refuse collection (discussed in detail in section 2.2.7), the distance travelled is made up of several parts. For this model it is assumed that the route travelled is from the depot to the collection round, then to the processing plant before returning to the depot. The model also assumes that each collection vehicle only makes one collection per fortnight, and uses a one-way trip distance of 3.67 miles from the collection route to the processing plant, and a return journey distance (estimated) of 6 miles for the journey to and from the vehicle storage Depot.

The fuel consumption for the kerbside scheme is determined using the same constants as for the refuse collection (section 2.2.7), which gives an energy consumption of approximately 13.84 MJ/collection.

2.2.4 Glass Processing Plant

The glass taken to the processing plant at the Docks is crushed and, if required, sorted using laser-separation equipment capable of sorting up to 40 tonnes per hour [14]. Energy consumption for the crushing/sorting has been estimated from electrical usage [14], allowing for an efficiency for electrical production of 30.2 %. This efficiency is based upon the fuel-split for electrical production within the UK [15] and the efficiencies of each of these production methods [16]. This gives an energy consumption of 9.6 MJ per tonne of glass processed, equating to a total annual energy consumption of approximately 13.2 GJ for the base-case scenario (1376.1 tonnes).

It should be noted that the model does not currently take into account on-site vehicle fuel consumption. The sub-model does, however, include material output parameters and options for changing these. For instance, how the cullet is to be used: traditionally, most of the cullet will go for re-use in glass manufacture, although it is increasingly being used for other means such as aggregates in road construction.

The sub-model allows specification of how much cullet goes to these alternative uses. In addition, the model assumes that any fines (that cannot be sorted and/or screened for contaminants such as ceramic material) and rejected material produced as a result of the crushing process are used as aggregates. The amount of fines and reject material can be specified, but is currently assumed to be 5 % and 1 % (of the mass of glass processed), respectively. Also, it is estimated [14] that 6.25 kg of waste material (light material separated during processing, such as paper and plastic labels, etc.) is produced per tonne of glass processed. This material is currently sent to landfill using an 11.5 tonne payload RCV, travelling a round-trip distance of 25.34 miles (determined using a route planner) to a Waste Transfer Station (assumed to be Otterbourne). The energy associated with the transfer of this material from the processing plant to the WTS is not included in the figure above and is calculated to be ~ 0.5 GJ/year; whereas the energy associated with transfer from the WTS to the landfill site is accounted for in the 'Landfill Transfer' sub-model (section 2.2.8).

2.2.5 Cullet Transfer

As was previously mentioned, the processing plant in Southampton is a new facility. Before it began operation, glass from Southampton was collected at local transfer stations before being transferred by truck to a processing facility in the north of England.

Now the glass is processed locally and the cullet transferred by ship to a port local to the glass manufacturing plant, and it is then transferred to the plant by truck. The model can, however, be run in either mode, i.e. transportation of the glass by truck and processed elsewhere, or local processing, then transfer by ship and/or truck.

If the model is run in "non-local" mode it is assumed that the bottle banks are first taken to the WTS at Otterbourne, using an average distance of 12.67 miles (estimated using a route planner). The model assumes that the processing plant is located adjacent to the glass manufacturing plant, and the glass to be processed is transferred from the WTS to the processing plant using a 25 tonne capacity truck, with an estimated 250 miles one-way journey distance. This gives an energy consumption per trip of 6.48 GJ, corresponding to an annual energy consumption of 333.1 GJ.

When the model is run in "local" mode, transfer to the processing plant is described as in section 2.2.2. Transfer of the cullet from the processing plant can then be made either by ship or by truck, depending on the destination/use of the cullet. Typically, for the situation in Southampton, cullet for use in glass manufacture will be transported by ship, since the manufacturing plants are concentrated in the northern part of England [17]. Conversely, it is assumed that most cullet destined for use as aggregates in road construction will be used locally.

For transfer of the cullet by ship, a ship load of 1200 tonnes is assumed [18]. From this, the number of ship trips per year can be calculated. It should be noted, however, that the number of trips is not rounded up/down to the nearest whole number, as was down with the stage 1 transport calculations. This is because it is assumed that the cullet produced from glass collected throughout Southampton makes up part of the load of the ship and, thus, contributes accordingly to the energy consumption of the ship. The remainder of the load is then made up of glass originating from other Waste Collection Authorities (WCAs) in Hampshire, etc.

The distance the ship travels can be varied as required (even allowing for global export of the cullet), but the model currently assumes that cullet transfer by ship is for use in UK glass manufacture. Here, transfer is to the port of Goole [18, 19], which is a distance of 381 nautical miles from Southampton [20]. The ship fuel consumption is based on actual fuel consumption data for the ship 'Duobulk', which is quoted as 12,050 litres Gas Oil [17] for the journey from Southampton to Goole. Based on this figure and the distance travelled, the model currently uses a fixed fuel consumption figure of approximately 27.5 litres per mile. This gives an energy consumption of approximately 1069 MJ/mile. Based on a ship load of 1200 tonnes this gives a value of 0.891 MJ/tonne/mile (amount of energy required to transport one tonne one mile). For the base-case recycling rate, this gives an annual energy consumption of 502.3 GJ.

It should be noted that this figure is based on use of a relatively small ship, which is used for transfer between national ports. If the cullet is exported long distances, it is likely that much larger ships will be used, part-filled with cullet. In this scenario it is recommended that different fuel consumption figures are used, and further development of the model will address this issue.

The cullet is then transferred from the ship at Goole to the glass manufacturing plant using a truck with an assumed capacity of 25 tonnes. It is presently assumed that the transfer distance is 75 miles, which is an estimated value. It is hoped that future development of the model will allow the user to choose both the location of the port and the manufacturing plant (or other end-use locations) from a database, and the transfer between the two will be automatically determined.

Fuel consumption for the truck is based on data from [6]. It should be noted, however, that the values used should be adjusted to account for the higher speeds travelled during transfer from Goole to the manufacturing plant, since the values used are currently for a speed of 30 km/hr. Further developments of the model will address this issue.

For transport by truck the energy consumption per trip is 2.0 GJ, corresponding to a total annual energy consumption of 102.8 GJ for the base-case scenario. Therefore, overall (ship plus truck) the annual energy consumption is 605.1 GJ.

Also included in the cullet transfer sub-model is transportation of any cullet that is to be sent for alternative uses, e.g. aggregates. Here, calculation of the energy consumption is the same as above for the truck stage of the transfer of the cullet sent for use in glass manufacture, also using a 25 tonne capacity truck. The only difference is the trip distance. Presently, for aggregates use this has been set to 25 miles (assumed one-way journey), since the aggregates will generally be used in, for example, local road construction.

For the base-case scenario, the model assumes that only the fines and reject material are sent for use as aggregates, with no diversion of the cullet away from glass manufacture. The energy consumption for transportation of the fines and reject material is approximately 719 MJ per trip, corresponding to 2.88 GJ/year (base-case scenario). The total energy consumption for the cullet transfer stage (for all uses) is approximately 608 GJ per year.

The model is also being developed further in order to examine the export of glass cullet abroad for use in glass manufacture, etc. This is of particular interest when tackling the issue of green glass, which is imported in to the UK in large quantities, but not generally produced here.

2.2.6 Glass Furnace

Cullet is used in glass manufacture in order to reduce the energy required to produce the melted glass. The following equation [21] is an estimate of this energy saving:

$$\text{Energy savings} = 0.25\% \times \% \text{ of scrap glass used} \qquad \textbf{(7)}$$

In order to determine the energy savings through increased cullet use it has been assumed that the amount of glass entering Southampton households each year is equal to the amount recycled plus the amount disposed of in the refuse, after accounting for labels, etc. The mass of the labels, etc. is assumed to be 0.625% of the total mass (section 2.2.4). For the base-case scenario the estimated amount of material (with labels, etc.) is approximately 5326 tonnes. Hence, the actual amount of glass is ~ 5292 tonnes. Then, it is assumed that all this glass is manufactured in one, average capacity, furnace. For this model an average furnace capacity of 204 tonnes per day glass output with a Specific Energy Consumption (SEC) for melting of 4.97 GJ/tonne for a cullet level of 39.5 % (17 % internal cullet) has been assumed [22, 23]. Based on this furnace capacity, the number of days of production required to make this amount of glass can be determined, allowing for breakages after production (assumed 17 % - i.e. the internal cullet level): approximately 6376 tonnes of glass must be manufactured in order to supply all of the glass presently used by Southampton's households. This requires 31.26 days of production at a capacity of 204 tonnes/day. The amount of cullet used in the furnace will then vary dependent upon the amount of glass recycled in Southampton. For instance, for the base-case scenario the amount of cullet used represents a level of 39.5 %, with a fixed level of external (non-Southampton) cullet of 2.58 %. In order to calculate the SEC for different cullet levels the following equation, based on the linear relationship given in equation (7), is used:

$$SEC_{RR} = SEC_{REF} \text{ x } \frac{\left[\frac{100 - (0.25 \text{ x } CL_{REF})}{100}\right]}{\left[\frac{100 - (0.25 \text{ x } CL_{RR})}{100}\right]} \tag{8}$$

where,

SEC_{RR} = Specific Energy Consumption at the desired recycling rate
SEC_{REF} = Reference SEC (at 39.5 % cullet), 4.97 GJ/tonne glass melted
CL_{REF} = Reference cullet level, 39.5 %
CL_{RR} = Cullet level at the desired recycling rate

It has been assumed that the use of cullet will only influence the melting energy, and not other stages of glass production, and peripheral electrical usage. The energy usage for the other stages, etc., is estimated at a fixed value of 2.03 GJ/tonne glass, assuming that the SEC of 4.97 represents 71 % of the total energy usage [22]. This gives a total energy consumption of 7.0 GJ/tonne glass produced for the base-case scenario. Account must, however, also be taken of the fact that some of the energy used for glass manufacture is electrical energy. Hence, the efficiency of electrical production (see section 2.2.3) must be taken into account. The amount of electrical usage during manufacture is estimated to be 14% of the total energy consumption [22]. Allowing for this gives an energy consumption of 9.265 GJ/tonne glass melted. This gives an annual energy consumption of 59077 GJ in order to produce all the domestic glass used in Southampton for the base-case scenario.

2.2.7 Refuse Collection

The energy consumption for the collection of the refuse is calculated in a similar manner to the other transport-based sub-models. The model calculates the theoretical number of weekly refuse collections based on a truck capacity of 11.5 tonnes [24] (the majority of RCVs in Southampton's fleet have a maximum allowable capacity of 11.5 tonnes). Future developments of the model will, however, modify this sub-model in order to incorporate actual refuse collection data from Environmental Pollution Act (EPA) returns [12] (i.e. weighbridge ticket data).

For the base-case scenario, with truck capacity of 11.5 tonnes, the number of collections per week is calculated as 126, based on 74815.2 tonnes/yr refuse (section 2.1). Next, the average distance travelled during each refuse collection round must be calculated. This distance is estimated using the following equation:

$$\text{collection miles per RCV} = \frac{\text{length of Southampton's roads}}{\text{number of weekly refuse collections}} \tag{9}$$

where the length of Southampton's roads is taken to be approximately 354.8 miles (571 km) [13], and the number of weekly collections for the base-case scenario is 126, giving a value of 2.836 miles/RCV per week (for a weekly collection frequency). This is likely to be the shortest distance travelled since it is a simplified method of calculating the distance. The model effectively considers Southampton to be one long road of length 354.8 miles. It is then assumed that the households are distributed evenly along this road, and that the refuse is distributed evenly amongst the households. Hence, the RCV will travel along the road a certain distance, as calculated above, until it is full of refuse, and continue this pattern until the full length of the road is travelled and all the waste collected.

A model is, however, currently being developed that is designed to determine the distance travelled more accurately, based on details of actual collection rounds. This model also takes into account travel from the Depot (where the RCV is located when not in use) to the start of the collection round, transfer of the refuse to the WTS, followed by travel back to the Depot.

The model will also be more accurate since it will also take into account the fact that the city is divided into several collection rounds/routes. There is generally a dedicated RCV for each collection round, and refuse is collected from different parts of each round on different days of the week. Therefore, each day the RCV will travel from the Depot to the start point for that day’s collection round. It will then collect refuse until it is full before taking the refuse to the WTS (or direct to a landfill site, etc.), and then return to the point on the collection round where it left off. The RCV team will then repeat this procedure until all the refuse from that day’s collection round has been collected. It will then return to the Depot after transferring the last load to the WTS.

It should be noted that the present model does not separately consider the distance travelled to/from the Depot: because of the way the model is set up, it will count this distance for every refuse collection. That is, it assumes that the RCV returns to the Depot every time it goes to the WTS, rather than leaving the Depot in the morning and only returning once the round had been completed. Hence, the distance travelled for this part of the journey will be overestimated.

Although the collection routes around the city are generally fixed, the point where the RCV leaves the route to take its load to the WTS will vary from week-to-week, due to the seasonal, etc. nature of waste generation. Hence, it is difficult to calculate the actual distance from the collection route to the WTS. Therefore, an average value is presently used in the model described here. The distance used is measured from the geographical centre of Southampton, since it is assumed that this will provide a simple average distance travelled by the RCV to the WTS. This distance to the WTS (assumed to be Otterbourne) is calculated from a route planner, and estimated to be 8.57 miles, giving a return journey length of 17.14 miles.

The fuel consumption of the RCV vehicle will depend on the mode of travel: it is assumed that for the transfer phase (travel to/from the Depot and WTS) the mode is "urban", and for the collection phase the mode is "collection" [6]. For the urban mode a fuel consumption of 25.59 MJ/mile is used (based on a speed of 30 km/hr – 18.6 miles/hr), whereas a value of 38.3 MJ/mile is used for the collection phase (speed of 10 km/hr – 6.2 miles/hr).

The sub-model also allows for variation in the collection frequency, which is necessary when including the dry recyclables scheme in a particular scenario. As will be discussed in section 2.3.3, the collection frequency for areas covered by the dry recyclables scheme will be half (26, i.e. fortnightly) that for areas covered by the PaperChain scheme (52, i.e. weekly). It should be noted that the assumption that, for a weekly collection frequency, there are 52 collections per year may not be strictly true due to public holidays, etc., such as the Christmas period.

The difference in collection frequency will make a difference to the energy consumption associated with the refuse collection: for each collection “week” it is necessary to collect refuse from across the whole of the city. Therefore, the collection distance will be 354.8 miles. For a fortnightly collection, this results in a distance of 9225 miles being travelled per year (354.8 x 26), compared to 18450 miles for a weekly collection (354.8 x 52). Hence, there will be a decrease in the energy consumption when using a fortnightly residual waste collection. In scenarios where, for example, the dry recyclables scheme operates in only part of the city (fortnightly refuse collection, with weekly collection in the remainder of the city) the collection distance is adjusted accordingly. For instance, with 50 % coverage the collection distance will be 177.4 miles (0.5 x 354.8).

It should be noted that the fact that the collection frequency is half does not also mean that the total energy consumption is also half for a fortnightly collection regime. This is because the sub-model also includes the energy consumption associated with transfer of the waste to a WTS, and return to the collection round. This part of the sub-model is independent of collection frequency, and is only dependent on the amount of material collected. For instance, for the base-case scenario the amount of refuse collected per year is approximately 74815 tonnes. This requires 6506 collections per year, based on a 11.5 tonne RCV capacity. Hence, the annual energy consumption associated with the transfer phase will be fixed and independent of the collection frequency, even though the energy consumption per collection "week" for this phase will be different.

With a weekly collection frequency, the energy consumption for the collection phase is approximately 109 MJ per collection, equivalent to ~ 707 GJ per year (for collection of all the refuse) for the base-case scenario. For a fortnightly collection frequency, the energy consumption for the collection phase is ~ 54 MJ per collection (~ 353 GJ per year). For the transfer phase the energy consumption is ~ 493 MJ per trip (irrespective of collection frequency), equivalent to ~2868 GJ per year (this is an average figure, since there are small differences between the values for weekly/fortnightly collection, due to rounding differences during the calculations procedure).

Hence, the total energy consumption per each refuse collection for the base-case scenario is approximately 547 MJ with weekly collection of the refuse, and ~ 439 MJ with fortnightly collection. This is equivalent to total annual consumptions of approximately 3580 GJ and 3216 GJ, respectively, for weekly (the default scenario for the glass model) and fortnightly collection of the refuse (for all the refuse for the base-case scenario). Multiplying the former value by the proportion of glass in the refuse (Table 2.1) gives an energy consumption associated with the glass of 189 GJ/year for weekly collection.

Presently, the model can allow for a choice of either a weekly or fortnightly collection of the residual waste, associated with those areas covered by the dry recyclables scheme. In the future the model will be developed so that the collection frequency can be varied independent of which recycling scheme is in operation, and also so that the choice of frequency can be wider (i.e. twice-weekly, etc.).

In the future actual RCV mileage (as indicated above) and fuel consumption data can be used in place of these estimations, which should both improve the accuracy of, and also simplify, the model. As well as development of the RCV model, data is being collected from a Road Relay Unit (RRU) fitted to an RCV operating in Southampton. The RRU measures and records numerous engine and vehicle parameters, including fuel consumption data. The data is being downloaded daily to provide both daily averages and a rolling average. This research is being undertaken in collaboration with Dennis Eagle (vehicle manufacturer), RTL Systems (supplier of RRU), WCR (vehicle owners) and Southampton City Council (WCA). It is hoped that data will be collected over a period of a full year, and should provide valuable information not only in relation to the fuel consumption (and the Energy Footprint project) but also in terms of other operational information for the RCV.

2.2.8 Landfill Transfer

Transfer of the refuse from the WTS to a landfill site is assumed to take place using a 20 tonne capacity truck, with a round-trip distance of 30 miles. In the future EPA data for the refuse collection rounds will be used to make the model more accurate by using actual disposal route information to give a breakdown of the destination of the refuse and determine (average) transfer distances.

The fuel consumption for transfer between the WTS and the landfill site is assumed to be 25.59 MJ/mile [6], with a 20 minute handling time for loading/unloading of the refuse (energy consumption 238 MJ/hr). This gives an energy consumption of 847 MJ/trip, corresponding to an annual energy consumption for the base-case scenario of approximately 3169 GJ (3741 trips). Multiplying this by the proportion of glass in the refuse gives an energy consumption associated with the glass of 167 GJ/year.

It should be noted that the energy consumption given here also includes the energy associated with transfer from the WTS to the landfill site of the waste material (labels, etc.) produced at the glass processing plant (see section 2.2.4). The energy consumption associated with this waste is, however, only a small amount (~0.4 GJ/year). Table B7 gives a breakdown of the energy consumption for the refuse collection and landfill transfer for each of the sub-categories found within the residual waste stream (refuse).

2.2.9 Incineration

Although glass is inert incineration is still included in the model as a waste management option. This is primarily to assess any impact recycling may have on incineration.

It is presently assumed that the refuse destined for incineration is transported direct to the incinerator after the collection round is completed. This is currently accounted for in the refuse collection sub-model, although further development of the model will account for it separately.

The incineration sub-model uses the net calorific value of the refuse, based on the composition determined in the refuse composition sub-model (section 2.1). The amount of energy produced from incineration of the waste is calculated using a conversion efficiency of 23.42% [25], representing the proportion of heat generated by the waste that is converted to electricity and exported to the electrical grid network.

Although the model varies the CV of the waste dependent upon its composition, the Marchwood incinerator has a nominal design point of 11 tonnes/hr at a net CV of 9.2 MJ/kg, with a minimum of 7 MJ/kg and maximum of 12.5 MJ/kg. The model does not, however, currently account for this (i.e. gives an error message if the calculated CV is outside the design envelope). For instance, the net CV calculated for the composition of refuse given in Table 2.1 is 16.31 MJ/kg, which is above the upper limit for the incinerator. This is because 1) the incinerator is designed to take mixed refuse from various areas throughout Hampshire and also other waste (the incinerator is designed to handle waste classified as 'mixed municipal waste' [26], European Waste Catalogue number 200301); 2) estimation of the refuse composition in Table 2.1 is based on data from 1999 and, so, is not necessarily accurate, and 3) estimation of the CV is based on the CV and moisture content of the individual components of the waste, without excess moisture, rather than the bulk CV (with bulk moisture) of the waste as delivered to the incinerator. These factors will be addressed in future developments of the model.

The incineration sub-model also determines the energy consumption for transfer of the solid waste produced by the incinerator: bottom ash (25% of waste input, after ferrous incineration residues removed), flue gas treatment (FGT) residues (4%), and ferrous incineration residues (5%) [25].

Calculation of the transport energy consumption associated with this is similar to those for transportation of the refuse from the WTS to the landfill site. The sub-model does, however, allow for choice of processing options for the bottom ash and FGT residues: landfill or recycling. It is assumed that all the ferrous residues are recycled. It is also assumed that any bottom ash or FGT residues are both disposed of at the same landfill site, with an assumed

round-trip distance of 30 miles, using a 20 tonne capacity truck [25] for transfer, with a 20 minute loading/unloading time. This gives an energy consumption for both the bottom ash and FGT residues of approximately 847 MJ/trip. Currently, this is the same value for the recycling option since it is not known at present how, if, or where the materials will be recycled. It is, however, likely that the bottom ash will be used as aggregates in, for example, road construction, and the FGT residues could possibly be used as feedstock in the chemicals industry [25].
It is also presently assumed that the ferrous residues are transported a round-trip distance of 30 miles, using a 20 tonne capacity truck. This also gives an annual energy consumption of approximately 847 MJ/trip.

As mentioned, in future developments of the model the bulk (excess) moisture will be accounted for in order to give a more realistic calorific value for the waste. In addition, further adaptation will be made so that the efficiency of the incineration process does not remain fixed, but will vary in relation to variation in the refuse composition. The efficiency is related to heat and process losses, most of which are assumed to be fixed when the incinerator is operating at a steady-state. Hence, the only variable heat loss will be that associated with the bottom ash, and the amount of bottom ash can be estimated from the ash content of the waste entering the incinerator. Therefore, the efficiency can be calculated based on the ash content of the waste. The ash content can also be used to calculate the amount of glass and metals contained within the incinerator bottom ash. In the present model the amount of bottom ash is kept at a fixed percentage of the input tonnage, and only ferrous incineration residues are considered. In addition, it is hoped that non-ferrous metals arising from the incineration process will also be included in the mass/energy balance for the incinerator, since Onyx Environmental hope that it will be possible to retrofit equipment to the incinerator that will allow separation from the bottom ash of non-ferrous metals, which can then be processed for recycling purposes [27].

2.3 PAPER & CARD FRACTION

For the paper/card waste fraction the following sub-models are employed:

1. Stage 1 transport (household to paper/card bank)
2. Stage 2 transport (paper/card bank to WTS/merchant)
3. Kerbside Collection (PaperChain & Dry Recyclables)
4. Mixed Dry Recyclables Materials Recovery Facility (MDR-MRF)
5. Stage 3 transport (WTS to MDR-MRF; WTS/merchant/MDR-MRF to Paper Mill)
6. Paper/Cardboard, etc. manufacture
7. Refuse collection
8. Landfill transfer
9. Incineration

Most of these sub-models are similar to those used for the glass model. Therefore, details will only be given of the different constants used for the paper/card sub-models. There are, however, some new sub-models, for example the MDR-MRF sub-model.

PaperChain Scheme:
Newspapers
Magazines

Paper Banks:
Newspapers
Magazines
Recycled Paper (non-packaging)

Cardboard Banks:
Card Packaging
Cardboard

Refuse Collection:
Newspapers, Magazines
Recycled Paper (non-packaging)
Paper, Card Packaging
Cardboard
Card non-packaging
Liquid Cartons
non-recyclable Paper

Dry Recyclables Scheme:
Newspapers
Magazines
Recycled Paper (non-packaging)
Paper Packaging
Card Packaging
Cardboard
Card non-packaging

Figure 2.7: Distribution of Paper/Card Sub-Categories amongst Collection Systems

Details of the different (sub-) categories of paper/card covered by the model (Table B1) are given below, and their distribution amongst the different collection methods shown in Figure 2.7, whilst the waste management structure for paper/card is shown in Figure 2.8.

Paper/Card (1):
Newspaper (1.01) (28.28 %)
Magazines (1.02) (21.39 %)
Recycled Paper (non-packaging) (1.03) (13.31 %)
Paper Packaging (1.04) (4.79 %)
Card Packaging (1.05) (15.00 %)
Cardboard (1.06) (3.67 %)
Card non-packaging (1.07) (0.96 %)
Liquid Cartons (1.08) (0.80 %)
non-recyclable Paper (1.09) (11.81 %)

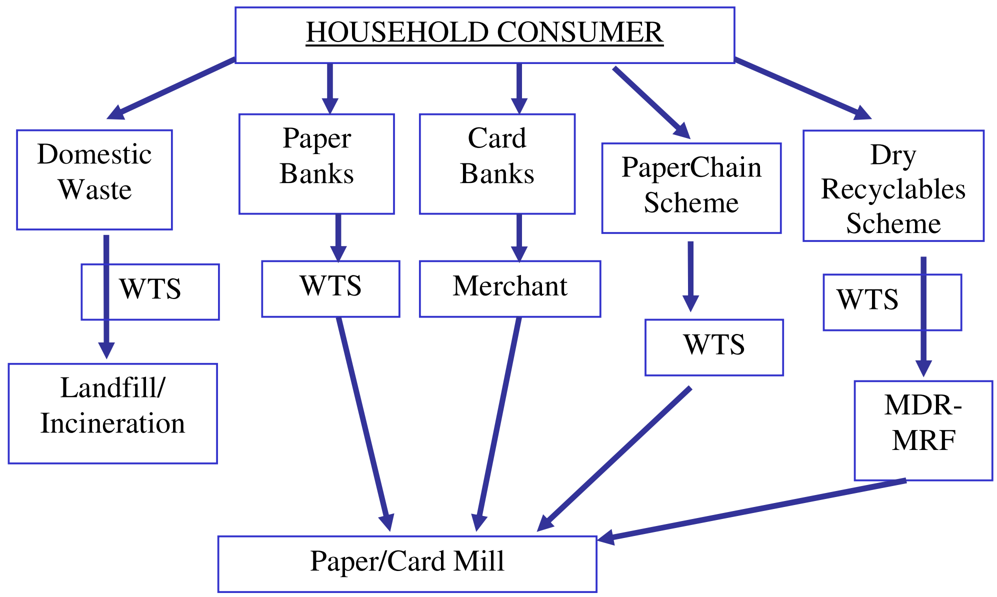


Figure 2.8: Paper/Card Waste Management Scheme

2.3.1 Stage 1 Transport

This sub-model is very similar to that for the glass model, except for the fact that the paper/card category of waste is divided into two sub-categories for collection of the material from bring-sites and HWRC sites: paper and card.

2.3.1.1 Paper/Card Bank at Bring-Site

For Southampton there are a total of 22 paper banks located at bring sites (average number for the period 2000-2002; [7]), corresponding to a site density of 1.012 per 10,000 inhabitants. There are presently no card banks located at bring-sites.

Using equation (1) gives a value of L = 0.264 miles and, from Figure 2.5, 35.45% of trips are made by car specifically for recycling, with an average return-journey trip of 0.528 miles. Hence, it can be seen that (compared to the glass model) a reduction in the number of banks in the city increases both the average distance travelled to the banks and also the proportion of people travelling to the banks specifically for recycling.

For the base-case scenario the amount of paper (see Figure 2.7 for sub-categories) taken to bring-sites in Southampton is 776.93 tonnes [28]. Calculation of the energy consumption for this material is carried out in the same manner as for glass (section 2.2.1.1), using the same constants for fuel consumption but using, where appropriate, the constants for distance travelled, etc., as given above. This gives an energy consumption of 3.42 MJ per trip, corresponding to an annual energy consumption of approximately 209 GJ (61,204 trips).

2.3.1.2 Paper/Card Bank at HWRC Site

For the base-case scenario 110.16 tonnes of paper and 184.63 tonnes of card per year are collected at the Endle Street HWRC site in Southampton [3, 12]. As shown in Table B6, this represents approximately 8 % of the total material taken to the site, which is equivalent to approximately 1.6 kg/vehicle.

From this, the number of trips required to transfer the yearly tonnages of the material to the HWRC site can be calculated, giving a figure of 180,343 trips. The energy associated with this number of trips is then calculated in the same manner as in section 2.2.1.2 (using the same constants for distance to site and fuel consumption). This gives the total energy consumption for transportation of all material to the site. Therefore, to calculate the energy consumption associated with, in this case, the paper/card fraction the total consumption value is multiplied by the proportion of paper/card taken to the site per trip (~8 %), which gives an annual energy consumption of approximately 478 GJ (179 GJ for the paper sub-categories and 299 GJ for the card sub-categories).

2.3.2 Stage 2 Transport

For the paper/card material, transfer from the banks at bring-sites or the HWRC are not to a single processing plant, as with the glass (section 2.2.2), although the general calculation methods and constants used are the same, or similar. Details of the difference between the paper/card model and the glass model are given below.

2.3.2.1 Bring-Site

As with the glass model, a 20 minute total loading/unloading time for the banks has been used. It is assumed that the paper banks are taken to Otterbourne WTS[2], with a return-journey trip distance of 17.14 miles. Also, it has been assumed that a skip lorry is used to transfer the paper bank to the WTS.

For the base-case scenario there are 105 paper bank collections per year [28]. Using the same calculation method and fuel consumption values as for the glass model (section 2.2.2.1), the energy consumption per paper bank collection is calculated to be approximately 518 MJ, corresponding to a total annual energy consumption for transfer of all the material from the paper banks of 54.4 GJ.

2.3.2.2 HWRC Site

At the Endle Street HWRC site separate facilities exist for the recycling of paper and card. The paper is collected using paper banks (two are situated on the site), whilst the card is collected using a 30.6 m3 sized skip (container; Figure 2.9). Not only is the paper and card material collected in separate containers, but it is also sent to different locations on the next stage of the recycling chain/cycle.

Material from the paper banks is taken to a WTS, assumed in the model to be Otterbourne, with a return-journey distance of 19.20 miles (determined from a route planner). It is assumed that the paper banks are transported to the WTS in the same manner as the banks located at bring-sites, i.e. with a skip lorry. Material from the card bin is taken to a waste merchant facility either located at Basingstoke or Gosport. For the purposes of this model, a single location has been chosen, namely Gosport. The bins are taken to Gosport using a Ro-Ro ('roll-on, roll-off') truck (Figure 2.10). The distance to Gosport is estimated using a route planner with Endle St. as the start point (postcode SO14 5FZ), and the waste merchant facility as the end point (PO12 1LR), giving a return-journey distance of 37.32 miles.

Using the above values for the distances travelled, and the same calculation methods and constants as used in section 2.2.2, the energy consumption per collection is approximately 571 MJ for the paper banks and approximately 1034 MJ for the card bin.

[2] The Otterbourne WTS is used in the present model as the default WTS. Future development of the model will allow, where appropriate, the location of the WTS to be varied.

acknowledgment: SCC, HWS; ©

Figure 2.9: Cardboard Skip Bin at Endle St. HWRC Site

For the paper banks, using an estimated value of 13 collections per year, gives an annual energy consumption of approximately 7.4 GJ. For the card bins, using an average, as determined from [3, 12], figure of 96 collections per year the corresponding energy consumption is approximately 99.3 GJ per year.
In the future, the model will be further developed to include a more accurate figure for the fuel consumption of the vehicles. This includes a figure of 6.5mpg [29] for the Ro-Ro truck used to transfer the material bins located at Endle St. HWRC site.

acknowledgment: SCC, HWS; ©

Figure 2.10: Truck used to Transport Cardboard Skip Bin

2.3.3 Kerbside Collection

Two types of kerbside collection schemes are considered in this model for the paper/card waste fraction: the PaperChain™ scheme and a Dry Recyclables scheme, which are described separately here. The model allows for concurrent operation of both collection schemes within the city, although not within the same area. That is, the dry recyclables scheme does not operate in those areas that are covered by the PaperChain scheme, and vice versa.

2.3.3.1 PaperChain Scheme

The PaperChain scheme was set up by Southampton City Council in November 2000**,** and until recently operated throughout the city, collecting newspapers, magazines, comics and leaflets. The scheme collects material from properties on alternate weeks (i.e. fortnightly), using a 3.5 tonne capacity truck (Figure 2.11) [28]. For the base-case scenario the average annual tonnage of material collected is 3194 tonnes [3], corresponding to an average number of collections per year of 1100 [3]. The number of collections is significantly more than the number of collections that would have been estimated from the maximum vehicle load capacity of 3.5 tonnes, which would give only 913 collections per year. Hence, the need to incorporate actual data into the model where available.

The material collected is taken to Otterbourne WTS, a return-journey distance of 17.14 miles. The model will be updated to also include the distances travelled to and from the Town Depot at the beginning and end of each collection shift, as has been discussed in section 2.2.7.

The distance travelled per collection (i.e. during the collection phase), based on a fortnightly collection, is calculated as 8.386 miles. This gives an energy consumption per collection (total; i.e collection phase plus transfer phase) of approximately 760 MJ, corresponding to a total annual consumption of approximately 836 GJ for the base-case scenario.

acknowledgment: SCC; ©

Figure 2.11: PaperChain Scheme Collection Vehicle

2.3.3.2 Dry Recyclables Scheme

In October 2003 Southampton City Council introduced a new kerbside scheme collecting dry recyclables, namely paper/card (see Figure 2.7 for details of the sub-categories), plastic

bottles/containers, and metal cans. The scheme, which was due to be phased in across the city over a two-year period, aims to substantially increase the recycling rate within the city over the next few years, and it has recently been reported [30] that a recycling rate of 35% is being achieved in the area of the city where the scheme was first introduced.
The scheme is presently[3] operating on a fortnightly basis, with alternate weekly collection of recyclables (blue-lidded, Figure 2.12) and residual waste (green-lidded) wheelie-bins from households. The dry recyclables scheme uses the same refuse collection vehicles as for the collection of the residual waste material. In order to prevent contamination of the dry recyclables the RCVs are washed out before they are used for the recyclables collection. Currently, the model does not account for the energy associated with this washing process.
Calculation of the energy consumption associated with the dry recyclables scheme is similar to that for refuse collection, using the updated and expanded refuse composition sub-model, full details of which are given in sections 2.1 and 2.2.7. As with refuse collection, it is assumed that the material is taken to Otterbourne WTS (return-journey distance of 17.14 miles). Presently, the model does not include travel to and from the Town Depot.
The main difference between the calculation method here and that for the refuse collection discussed in section 2.2.7 is the number of collection "weeks" per year. As mentioned above, the dry recyclables scheme operates on alternate weeks, which gives 26 collection "weeks", compared to 52 for the refuse collection sub-model used for the glass model. The effect of this has been discussed in greater detail in section 2.2.7.
The energy consumption associated with the collection of the dry recyclables is calculated to be approximately 439 MJ/collection. Details are not given here of the energy consumption to transfer a certain amount of material, since the base-case scenario does not include operation of the dry recyclables scheme.

acknowledgment: SCC; ©

Figure 2.12: Introduction of the new Blue-Lidded Bins for the Dry Recyclables Kerbside Collection Scheme for Southampton

[3] The expansion of the scheme was suspended in March 2004, subject to an independent assessment in order to address the issue of the choice of collection frequency (fortnightly or weekly) for the residual waste. (see also section 3.3.4)

2.3.4 Mixed Dry Recyclables Materials Recovery Facility (MDR-MRF)

For the paper/card model, a MDR-MRF sub-model has been introduced. The MDR-MRF (or abbreviated to MRF) is mainly used for the separation of the materials collected from the dry recyclables scheme. The MDR-MRF can, however, also be used to separate other recyclables collected by other means; for example, material from paper banks, mixed metals can banks, and plastics banks.

In order to determine the energy consumption for the MRF and, in particular, the consumption associated with the paper/card fraction, it is necessary to have an energy and materials balance for such a facility. For this model actual data has been used for the Portsmouth MRF [31], operated by Onyx Hampshire Ltd. Further details are given in Appendix C.

The materials balance data (Table C1) has been used to apportion energy (electrical and fuel consumption, Table C2) usage for the different materials entering the MRF. Table C1 only gives the "mass-out" tonnages, i.e. recyclables and residuals leaving the MRF. Therefore, in order to calculate the proportion of materials entering the MRF (and the energy usage associated with them), it is assumed that, firstly, the 'fibre residue' material is only associated with processing of the paper fraction. Secondly, the 'residue' material sent for disposal is associated with all the materials entering the MRF. Here, it is assumed that each dry recyclables material produces the same amount of residue material (Table C1), and this is a fixed proportion. For any other material (essentially 'contaminants', which can, for the purposes of the model, include any of the sub-categories of refuse as specified in the refuse sub-model, section 2.2.7) it is assumed that these pass through the MRF intact as material sent for residue disposal; essentially, they have a 100 percent "reject" level. Hence, from the above, the material inputs can be back-calculated from the material outputs, and these inputs are given in Table C3.

It has been assumed that variation in the composition of the material entering the MRF does not significantly affect the electricity and fuel usage associated with operation of the MRF. Therefore, from the total tonnages of materials given in Table C3, and the electrical/fuel usage given in Table C2, values per tonne of material processed can be calculated. These are 14.98 kWh electricity/tonne and 0.128 litres red Diesel/tonne, respectively. From this, the energy consumption per tonne of material processed can be calculated, using the efficiency of electricity production (30.2%, as estimated using [15, 16], section 2.2.3), and the density/calorific value for red diesel. This gives values of 178.58 MJ/tonne for electrical usage and 4.85 MJ/tonne for fuel usage (mobile plant). From this, it is simply a matter of multiplying these values by the tonnages of each material entering the MRF in order to determine the energy consumption for processing each material (e.g. the paper/card fraction).

In addition, the MDR-MRF sub-model includes calculations to determine the energy consumption associated with transportation of the material exiting the MRF to the next stage in the recycling/disposal chain/cycle. The destinations used to determine the energy consumption are given in Table C1. It should be noted that the model presently assumes return-journey distances, i.e. twice the distances given in Table C1. Calculation of the transport energy consumption is then similar to the other calculations for transport described in this report, using fuel consumption constants for urban travel and loading/unloading (assumed to be 20 minutes total for all materials, independent of type of material, etc.) as given in section 2.2.2.1. For the purposes of the paper/card model, those paper sub-categories other than newspaper/magazines and the card sub-categories are assumed to be 'mixed paper', which is sent to Taplow mill for processing.

The fibre residue material is sent to Slough Heat and Power facility [31]. Currently, the model does not account for the energy produced from thermal processing of this material, nor

disposal of the associated residues produced from its combustion. This will be considered in future models, since the produced energy could (significantly) affect the overall energy consumption associated with the processing of material at the MRF.
The contaminants ('residue') are disposed of at the Blue Haze landfill site. However, this material could also be sent for incineration, or other thermal processing and it is intended that the option of thermal processing of the residue material will be included in future developments of the model.

2.3.5 Stage 3 Transport

This stage covers the transfer of the paper/card material to the paper/cardboard mill, and also transfer of the dry recyclables material from the WTS to the MDR-MRF. This generally involves different routes, depending on the original source of the material, and is as follows:

- material from the Paper banks (bring-site and HWRC) are transferred from the WTS (assumed Otterbourne) to the Aylesford paper mill using a 20 tonne capacity truck (assumed – see Table C1), travelling a round-trip distance of 133.3 miles (determined from a route planner).
- material from the HWRC card bin is transferred from the waste merchant in Gosport to the St. Regis mill in Taplow using an assumed truck capacity of 20 tonnes, travelling a round-trip distance of 135.2 miles, determined from a route planner.
- material from the PaperChain scheme is transferred from the WTS at Otterbourne to the Bridgewater mill, Ellesmere Port using a 20 tonne capacity truck, travelling a round-trip distance of 388.4 miles (route planner).
- dry recyclables material are transferred from the WTS (Otterbourne) to the MRF (Portsmouth) using a 20 tonne capacity truck, travelling a round-trip distance of 53.5 miles (route planner).
- material from the MDR-MRF follows several different routes, and has already been discussed in the previous section.

For the base-case scenario this gives the following energy consumption figures, using the standard fuel consumption figures and loading/unloading times (20 minutes) as before:

- for the Paper banks material there is an energy consumption of approximately 3.5 GJ/trip. With 45 trips made per year (based on the amount transferred and truck capacity), this results in an annual energy consumption of 157 GJ.
- for the HWRC card bin material, the energy consumption per trip is approximately 3.54 GJ, with 10 trips per year, resulting in an annual energy consumption figure of 35.4 GJ.
- for the PaperChain scheme material, there is an energy consumption of approximately 510 GJ/trip. With 160 trips made per year, this results in an annual energy consumption of 1602 GJ.
- for transfer of the dry recyclables material from the WTS to the MDR-MRF there is an energy consumption per trip of approximately 1.45 GJ. Since the scheme is not used in the base-case scenario, no annual figures have been quoted here.

2.3.6 Paper/Card Manufacture

The sub-model for the manufacture of paper/card uses simple calculations to determine the overall energy consumption required to produce the tonnages of paper/card that Southampton uses in a year. This is similar to the concept used in the glass model (see section 2.2.6). The amount of paper/card “entering” Southampton is calculated from the amount of paper/card in the refuse (including liquid cartons and non-recyclable paper, since this still has to be manufactured), and the amount of paper/card recycled. For the base-case scenario this equates to a total of 23,562 tonnes per year.

It is then assumed that the manufacturing process for paper, cardboard, and other paper-based material is similar and that the energy requirements for each does not vary significantly. The model then uses the energy consumption figures for the production of paper from raw material (27.84 GJ/tonne produced virgin paper, [32]), and from recycled material (22.25 GJ/tonne produced recycled paper, [32]). For production of paper from recycled material it has been assumed that losses of 15% are incurred during re-processing of the recovered paper/card [32].

From this, the proportion of recycled and virgin material required to produce 23,562 tonnes per year of paper/card can be determined for different material recycling rates. For the base-case scenario the figure is approximately 15.4% recycled material.

The energy consumption required to produce the paper/card is then calculated separately for the virgin (555,021 GJ; 87.3 %) and recycled paper (80,675 GJ; 12.7 %) and then summed to give the total annual energy consumption of approximately 635,723 GJ.

Also included in the paper mill sub-model is the transport of the waste material associated with the losses incurred during processing of the recycled material. It is assumed that this material is sent to landfill, using a 20 tonne truck travelling a round-trip distance of 30 miles. The annual energy consumption for this transfer (base-case scenario) is approximately 27.1 GJ. This is only small in relation to the total energy consumption, but it might also be interesting to develop the model so that the possibility to use the waste material for power/heat production is included.

2.3.7 Refuse Collection

The energy consumption associated with the transfer of the refuse from the household to the WTS is ~ 547 MJ per individual refuse collection, equating to ~923 GJ/year for transfer of the paper/card fraction only (see Table B7).

2.3.8 Landfill Transfer

The landfill transfer sub-model for the paper/card model is the same as the sub-model used for glass (section 2.2.8). Using the same methodology, the annual energy consumption figure associated with the paper/card fraction of the refuse is ~817 GJ/year. (~3168 GJ/year for all the refuse for the base-case scenario; see Table B7).

2.3.9 Incineration

The incineration sub-model for the paper/card model is also the same as for the glass model (2.2.9). Presently, the energy production from incineration does not break down the annual figure down into the energy produced for each type of material, although it can be split up into amount of energy, attributed on a mass basis only, associated with each material present in the residual waste stream.

2.4 PLASTICS FRACTION

For the plastics waste fraction the following sub-models are employed:

1. Stage 1 transport (household to plastics bank)
2. Stage 2 transport (plastics bank to WTS)
3. Kerbside Collection (Dry Recyclables)
4. MDR-MRF
5. Stage 3 transport (WTS/MDR-MRF to plastics sort MRF)
6. Plastics Sort MRF
7. Plastics processing
8. Refuse collection
9. Landfill transfer
10. Incineration

Most of these sub-models are similar to those used for the paper/card model. Therefore, details will only be given of the different constants used for the plastics sub-models. There are, however, some new sub-models, e.g. plastics sort MRF, which are described in more detail in the next part of the report.

Plastics Banks:
DENSE PLASTICS:
PET Clear/Coloured Bottles
HDPE Clear/Coloured Bottles
PVC Clear/Coloured Bottles

Dry Recyclables Scheme:
DENSE PLASTICS:
PET Clear/Coloured Bottles
HDPE Clear/Coloured Bottles
PVC Clear/Coloured Bottles

Refuse:
PLASTIC FILM:
Refuse Sacks & Carrier Bags
Film packaging
Film non-packaging
DENSE PLASTICS:
PET Clear/Coloured Bottles
HDPE Clear/Coloured Bottles
PVC Clear/Coloured Bottles
Food Packaging
Non-Food Packaging

Figure 2.13: Distribution of Plastics Sub-Categories amongst Collection Systems

Details are given below of the different (sub-) categories of plastics (as given in Table B1) covered by the model. Their distribution amongst the various possible collection systems is shown in Figure 2.13**,** whilst the waste management structure for plastics is given in Figure 2.14.

Plastic Film (2) (57.20 %):
Refuse sacks & Carrier Bags (2.01) (54.24 % of category 2; 31.03 % of plastics fraction)
Film – packaging (2.02) (43.50 %; 24.89 %)
Film - non-packaging (2.03) (2.26 %; 1.29 %)

Dense Plastic (3) (42.80 %):
PET Clear Bottles (3.01) (9.48 %; 4.06 %)

PET Coloured Bottles (3.02) (1.58 %; 0.68 %)
HDPE Clear Bottles (3.03) (3.95 %; 1.69 %)
HDPE Coloured Bottles (3.04) (7.90 %; 3.38 %)
PVC Clear Bottles (3.05) (1.58 %; 0.68 %)
PVC Coloured Bottles (3.06) (0.00 %; 0.00 %)
Food Packaging (3.07) (32.47 %; 13.90 %)
non-Food Packaging (3.08) (6.04 %; 2.59 %)
Other (3.09) (37.01 %; 15.84 %)

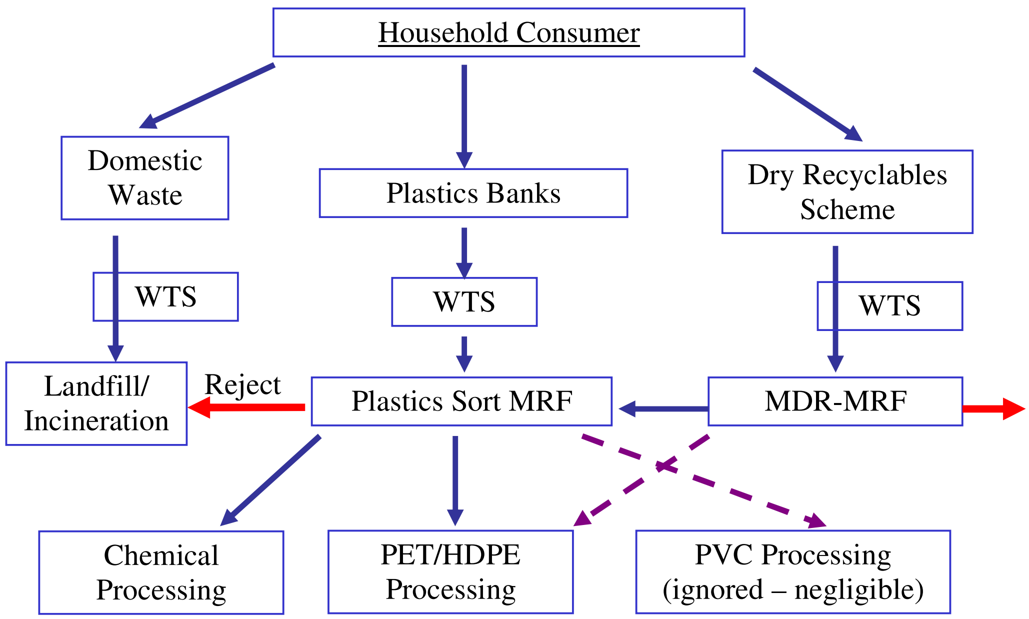


Figure 2.14: Plastics Waste Management Scheme

2.4.1 Stage 1 Transport

As can be seen from Figure 2.13 only material from the dense plastics category is collected via the plastics banks. Also, within this category only three types of plastic are collected: PET, HDPE and PVC. Furthermore, due to the present sorting technology employed at the MDR-MRF considered in this model, only plastic bottles (/containers) are collected.

As with the other waste materials detailed earlier, there is a fixed ratio of the split between the amount of material collected via bring-sites and via the HWRC. For the base-case scenario 82.65 % of plastics are collected via the bring-sites, and 17.35 % via the HWRC site. In the base-case scenario, plastics are only recycled via plastics banks and the amount recycled (53.174 tonnes in total) represents an overall recycling rate for the plastics fraction of only 0.46 %. Taking the dense plastics (waste category 3) in isolation, the amount recycled represents 1.07 % of the amount available; and for the plastics sub-categories that are actually collected (HDPE, PET, PVC) it represents a recycling rate of 4.36 %. Each figure represents the ratio of the amount recycled (of each category, or sub-category) to the amount available (of each category, or sub-category).

2.4.1.1 Plastics Bank at Bring-Site

For the base-case scenario, there are five plastics banks located throughout Southampton [7], corresponding to a site density of 0.23 sites per 10,000 inhabitants. Using equation (1) gives an average return-journey distance of 1.107 miles, which corresponds (Figure 2.5) to approximately 37.65% of trips being made specifically for recycling.

For the base-case scenario the amount of plastics recycled via the bring-sites is 43.95 tonnes [28], representing a recycling rate of 3.6 % (for HDPE, PET, PVC plastics) via these banks. The calculation of the energy consumption for transfer of this material from the household is similar to that for glass and paper/card. It is assumed, however, that the amount of plastics taken to a bring-site per trip will be lower than for these other materials, since plastics have a relatively high volume-to-weight ratio. Hence, an estimated mass of 0.75 kg per trip has been assumed. This value is based on simple calculations carried out by the authors, as given in Appendix D.

Using the above constants/values the energy consumption for transfer of the plastics to the bring-sites is estimated to be 7.17 MJ per trip, representing a total annual energy consumption of 158 GJ (for 22,064 trips).

2.4.1.2 Plastics Bank at HWRC Site

For the base-case scenario 9.224 tonnes of plastics are recycled via the plastics bank at the HWRC site. This represents a recycling rate of 0.76 % (for HDPE, PET, PVC sub-categories) via this bank. From Table B6 in the Appendix the plastics fraction represents ~ 0.26 % of the amount of material taken to the HWRC per trip, equivalent to ~ 0.05 kg.

The energy consumption associated with transfer of the plastics is 0.083 MJ per trip, giving a total annual energy consumption of 14.95 GJ (180,343 trips per year).

2.4.2 Stage 2 Transport

Transfer of material from the plastics banks at both the bring-sites and the HWRC site is to a local WTS (assumed to be Otterbourne), and it is assumed that the banks are transferred to the WTS using a skip lorry. An average return-journey distance of 17.14 miles is used for transfer from the bring-sites, whereas a value of 19.20 miles is used for transfer from the HWRC. Both values have been determined using a route planner.

A default loading/unloading time for the banks of 20 minutes has been used, which is the same as for the other recycling banks. For the base-case scenario there are 169 collections per year from the bring-sites [12] and 29 collections from the HWRC site [28].

This gives a total annual energy consumption of 87.5 GJ and 16.7 GJ, respectively, for transfer from the bring-sites and HWRC.

2.4.3 Kerbside Collection

Presently, the model only considers kerbside collection via the dry recyclables scheme. In the future the model will also include the option for the separate kerbside collection of source segregated plastics. The dry recyclables scheme only collects HDPE, PET and PVC bottles/containers, and it is the energy consumption associated with these materials that is calculated in the same manner as for the paper/card waste fraction.

2.4.4 MDR-MRF

Determination of the energy consumption associated with the separation of the plastics at the MDR-MRF is the same as for the paper/card fraction (section 2.3.4). The only difference in the calculations is the destination of the plastics leaving the MRF, details of which are given in Table C1.

2.4.5 Stage 3 Transport

This is transfer of the collected material to the next stage of the recycling chain/cycle. For the plastics fraction, this is transfer from the WTS to the MDR-MRF (dry recyclables); from the MDR-MRF to the plastics sort MRF (dry recyclables); and from the WTS to the plastics sort MRF (plastics banks):

- Transfer of the dry recyclables from the WTS to the MDR-MRF is the same as described for the paper/card fraction, as detailed in section 2.3.5.
- Details of the distance travelled and truck size for transfer from the MDR-MRF to the plastics sort MRF are given in Table C1. Using these input parameters gives energy consumption values per trip of 11.8 GJ.
- Transfer of material from the WTS to the plastics sort MRF is using a 20 tonne capacity truck travelling a return-journey distance of 405.3 miles. Using these values gives an energy consumption per trip of approximately 10.45 MJ per trip, representing an annual energy consumption of 31.35 GJ.

2.4.6 Plastics Sort MRF

Presently the model assumes that the MDR-MRF described in section 2.4.4 only separates the plastics fraction from the other dry recyclables [27]. The plastics fraction is then sent to a plastics sort MRF for further separation into the different types of plastics: namely HDPE, PET and PVC. Future development of the model will also examine the sorting of the plastics into the different types at the MDR-MRF.

As well as separating plastics sent from the MDR-MRF, the plastics sort MRF also sorts plastics collected via the plastics banks. The model currently assumes that the energy consumption from electrical usage, on-site vehicle fuel consumption, and material losses (8.42 %) are estimated to be the same as those for the MDR-MRF. It is also assumed [27] that the PVC fraction is rejected and sent to landfill. It is intended that future development of the model will examine both the possibility to incinerate this fraction, and also to send it for re-processing, and will investigate the actual energy consumption associated with operation of the plastics sort MRF.

The model assumes that the HDPE and PET fractions are sent to different locations, although the model presently assumes a default distance of 50 miles for each. Transfer for both fractions is using an 18 tonne capacity truck. This gives an energy consumption per trip of 2.64 GJ, corresponding to an annual energy consumption of 6.68 GJ for the base-case scenario. For the PVC fraction and rejected material, transfer is with a 10 tonne capacity truck to a landfill site with a default distance also of 50 miles. This also gives an energy consumption of 2.64 GJ/trip, but the annual energy consumption for the base-case scenario is 2.01 GJ. The annual consumption for the sort MRF itself is estimated at 9.75 GJ, giving a total energy consumption for the plastics sort MRF sub-model of 18.44 GJ/year.

2.4.7 Plastics Processing

Currently the model only considers conventional processing of recycled plastics, and not chemical processing. The sub-model is similar to those for glass and paper/card, and determines the energy consumption required to produce the amount of plastics that is used annually in Southampton. Production of HDPE and PET plastics only are, however, considered, since these are the only plastics sent for reprocessing in the model. The model also assumes that the recycled material is used to produce the same type of products, i.e. plastics bottles. This is not true in some cases, particularly where the original containers are used for food stuffs. As long as the recycled material is, however, used to offset the production of plastics (no matter how, or in what form, they are used) from virgin material,

then the model is still valid in terms of calculation of the energy savings through use of recycled material.
It should be noted that only those sub-categories of plastics that are presently recycled are included in the estimation of the amount of plastics used in Southampton. Other sub-categories that are, or may include, plastic types that could be recycled are not included in the estimation. For example, waste category 'Dense Plastics', sub-category 'Food Packaging'. This is often HDPE plastic, but is not recycled because it is generally not suitable for the sorting facilities presently found at MDR-MRF plants, or they are heavily contaminated. In addition, the breakdown of the different types of plastics within these sub-categories is not known. Hence, they are excluded from the estimated tonnages used. It is possible, however, to adjust the model to include all sub-categories of plastics.

2.4.7.1 HDPE Production

The amount of HDPE dense plastics used in Southampton annually is estimated at 590 tonnes, based on the amount of material recycled and the amount in the refuse (Table B1), for the base-case scenario. The amount of HDPE plastics recycled is determined from the amount of plastics recycled via the plastics banks (base-case level), with the assumption that the percentage split of the different types of plastics recycled (HDPE/PET/PVC) is the same as the split of these types of plastics in the refuse (which can be determined from Table B1).
The energy consumption associated with the production of one tonne of virgin HDPE (excluding feedstock energy) is 33.25 GJ [33], whereas for recycled HDPE it is 7.62 GJ [33]. For the production of HDPE from recycled material it has been assumed that a loss of 15 % is incurred during processing of the recovered HDPE [34]. From this, the proportion of recycled and virgin material required to produce 590 tonnes per year of HDPE plastic can be determined for different material recycling rates. For the base-case scenario the proportion is approximately 3.4% recycled material, and 96.6% virgin material.
The energy consumption required to produce the HDPE plastic is then calculated separately for the virgin and recycled plastic and then summed to give the total annual energy consumption of approximately 19103 GJ (equivalent to 32.38 GJ/tonne HDPE produced). This includes the energy associated with the transport of the waste material associated with the losses during processing of the recycled material. It is assumed that this material is sent to landfill, using a 20 tonne truck travelling a round-trip distance of 30 miles. The annual energy consumption for this transfer (for the base-case scenario) is approximately 0.15 GJ. This is only small but, as with the paper/card sub-model, it might also be interesting to develop the model so that the possibility to use the waste material for power/heat production is included, especially since it would be expected that this material would have a relatively high calorific value.

2.4.7.2 PET Production

The amount of PET dense plastics used in Southampton annually is estimated at 551 tonnes, based on the amount of material recycled and the amount in the refuse (Table B1), for the base-case scenario. The amount of PET plastics recycled is determined in the same manner as for the HDPE plastics.
The energy consumption associated with the production of one tonne of virgin PET (excluding feedstock energy) is 35.89 GJ [35], whereas for recycled PET flakes it is 2.86 GJ [35]. For the production of PET from recycled material it has been assumed that a loss of 13.64 % is incurred during processing of the recovered PET [36]. From this, the proportion of recycled and virgin material required to produce 551 tonnes per year of PET plastic can be

determined for different material recycling rates. For the base-case scenario the proportion is 3.45 % recycled material, and 96.55 % virgin material.

The energy consumption required to produce the PET plastic is then calculated separately for the virgin and recycled plastic and then summed to give the total annual energy consumption of approximately 19134 GJ (34.75 GJ/tonne PET produced). This includes the energy associated with the transport of the waste material associated with the losses during processing of the recycled material, calculated in the same manner as for the HDPE, giving an annual energy consumption of 0.13 GJ.

2.4.8 Refuse Collection

The energy consumption associated with the transfer of the refuse from the household to the WTS is ~ 547 MJ per individual refuse collection, equating to ~554 GJ/year for transfer of the plastics fraction only (see Table B7).

2.4.9 Landfill Transfer

The landfill transfer sub-model for the plastics model is the same as the sub-model used for glass (section 2.2.8). Using the same methodology, the annual energy consumption figure associated with the plastics fraction of the refuse is ~491 GJ/year (Table B7).

2.4.10 Incineration

For details of the incineration sub-model refer to section 2.2.9.

2.5 METALS FRACTION

For the metals waste fraction the following sub-models are employed:

1. Stage 1 transport (household to metals bank/container)
2. Stage 2 transport (metals bank/container to MRF/scrap merchant)
3. Kerbside Collection (Dry Recyclables & Bulky Waste Collection)
4. MDR-MRF
5. Stage 3 transport (WTS to MDR-MRF, MDR-MRF/scrap merchant to Metals Processing)
6. Scrap Merchant
7. Metals Processing
8. Refuse collection
9. Landfill transfer
10. Incineration

Most of these sub-models are similar to those used for the other models. Therefore, details will only be given of the different constants used for the metals sub-models. There are, however, some new sub-models (e.g. scrap merchant). It should also be noted that the model does not presently include a sub-model for the collection of Bulky Goods, although this will be included in future developments of the model.

Mixed Metals Can Banks:
FERROUS:
Food Cans
Beverage Cans
NON-FERROUS:
Beverage Cans - Aluminium
Aluminium Food Cans

Refuse:
FERROUS METALS:
Food Cans
Beverage Cans
Batteries
Aerosols
Other Ferrous
White Goods
NON-FERROUS METALS:
Aluminium Foil
Beverage Cans - Aluminium
Aluminium Food Cans
Other

Metals Skip:
FERROUS:
Other Ferrous
NON-FERROUS:
Other

HWRC White Goods:
FERROUS:
White Goods

HWRC Batteries Container:
FERROUS:
Batteries

Bulky Waste Collection:
FERROUS:
White Goods

Dry Recyclables Scheme:
FERROUS:
Food Cans
Beverage Cans
NON-FERROUS:
Beverage Cans - Aluminium
Aluminium Food Cans

Figure 2.15: Distribution of Metals Sub-Categories amongst Collection Systems

Details are given below of the different (sub-) categories of metals covered by the model (Table B1), and their distribution amongst the various possible collection systems is shown in Figure 2.15, whilst the waste management structure for metals is given in Figure 2.16.

Ferrous Metals (8) (81.23 %):
Food Cans (8.01) (48.38 %; 39.30)
Beverage Cans (8.02) (1.01 %; 0.82 %)
Batteries (8.03) (1.91 %; 1.55 %)
Aerosols (8.04) (3.97 %; 3.22 %)
Other Ferrous (8.05) (39.81 %; 32.34 %)
White Goods (8.06) (4.92 %; 4.00 %)

Non-ferrous Metals (9) (18.77 %):
Aluminium Foil (9.01) (25.75 %; 4.83 %)
Beverage Cans - Aluminium (9.02) (21.81 %; 4.09 %)
Aluminium Food Cans (9.03) (8.72 %; 1.64 %)
Other (9.04) (43.71 %; 8.20 %)

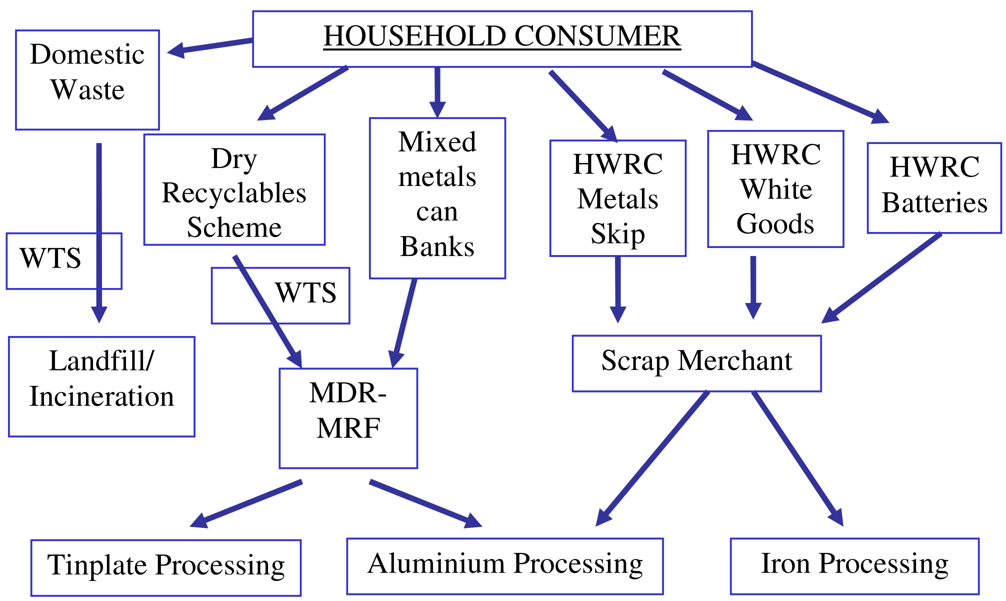


Figure 2.16: Metals Waste Management Scheme

2.5.1 Stage 1 Transport

As can be seen from Figure 2.15, there are several collection options for the metals waste fraction, mainly at the HWRC site, and these are detailed in this section.

The model presently assumes that there is a fixed ratio of the split between the amount of material (mixed metal cans only) collected via bring-sites and via the HWRC, based on the split for the base-case scenario (95.5 % collected via the bring-sites). Hence, if the amount of mixed metals cans recycled is increased then the ratio between the amount collected via

bring-sites and the HWRC site remains fixed. The model can, however, be easily modified to allow the ratio to be varied.
The overall recycling rate for the ferrous and non-ferrous metals waste categories is 27.6 % and 5.6 %, respectively. This corresponds to an overall recycling rate for the metals fraction of 23.5 %. Each figure represents the ratio of the amount recycled (of each category, or later sub-category as given later) to the amount available (of each category, or sub-category).

2.5.1.1 Metals Bank at Bring-Site

For the base-case scenario, there are five mixed metals can banks located throughout Southampton [7], corresponding to a site density of 0.23 sites per 10,000 inhabitants. Using equation (1) gives an average return-journey distance of 1.107 miles, which corresponds (Figure 2.5) to approximately 37.65 % of trips being made specifically for recycling.
For the base-case scenario the amount of mixed metals cans recycled via the bring-sites is 32.79 tonnes [28]. This corresponds to a recycling rate of 1.53 % for those sub-categories of metals recycled via the mixed metals can banks. That is, 1.53 % of the total available amount of mixed metals cans is recycled via the bring-sites.
The calculation of the energy consumption for transfer of this material from the household is similar to that for glass and paper/card, with a mass of 4.5 kg being taken to the bring-site per trip.
Using the above constants/values, the energy consumption for transfer of the mixed metals cans to the bring-sites is estimated to be approximately 7.17 MJ per trip, representing a total annual energy consumption of 19.7 GJ (for 2744 trips).

2.5.1.2 Metals Bank at HWRC Site

There are several collection facilities for metals located at the HWRC: mixed metals can bank, mixed ferrous/non-ferrous metals skip, white goods, and batteries. The sub-categories of metals collected via each facility are given in Figure 2.15. Details of the tonnes collected via each are as follows (each recycling rate refers to those sub-categories recycled via each particular facility, not the overall metals fraction recycling rate):

a) mixed metals can bank - 1.53 tonnes (0.07% recycling rate).
b) metals skip (30m^3) - 795.14 tonnes ‘Other ferrous’ sub-category (52.66% recycling rate) and 44.52 tonnes ‘Other’ (non-ferrous) sub-category (11.62% recycling rate). This gives a total of 839.66 tonnes collected (44.36% recycling rate). For the purposes of the model it is assumed that only the ‘Other ferrous’ and ‘Other’ (non-ferrous) sub-categories are recycled via the metals skip.
c) White goods - 186.6 tonnes. The model presently assumes that this corresponds to a 100% recycling rate, since it is assumed that there are no white goods present in the refuse. Also, bulky waste collection of white goods is not yet included in the model. Neither are other possibilities for disposal/collection, such as illegal dumping or charity shops/schemes presently considered. It is intended that data on these other options for collection/disposal/recycling will be considered in future developments of the model. In addition, the model also presently assumes that all white goods collected via the HWRC site are collected separately from other metals. This may not be strictly true, since some white goods may be collected via the metals skip, and some may be considered bricabrac.
d) Batteries - 34.85 tonnes (48.09 % recycling rate). The model assumes that all types of batteries are collected via the HWRC site (i.e small household batteries and, e.g., car batteries).

As with the other waste fractions it is assumed that the amount of material taken to the HWRC site per trip is a fraction of the total amount taken (20 kg), based on the percentage of each material found at the site. For the different collection facilities described above the following breakdown for the base-case scenario is obtained, as shown in Table 2.4. This part of the model will, however, have to be developed further since the model needs to be more flexible in order to allow adjustment under certain circumstances. For example, white goods generally weigh in excess of 20 kg, which is the assumed load per trip.

Collection Facility	Tonnes/year taken to HWRC	Fraction of total material taken to HWRC [%]	Fraction of Metals taken to HWRC [%]	Mass taken to HWRC [kg/trip]
Mixed metals can bank	1.53	0.04	0.14	0.01
Metals skip:				
ferrous	795.14	22.05	74.83	4.41
non-ferrous	44.52	1.23	4.19	0.25
White goods	186.60	5.17	17.56	1.03
Batteries	34.85	0.97	3.28	0.19
Totals:	**1062.64**	**29.46**	**100.00**	**5.89**

Table 2.4: Breakdown of Metals Material Taken to HWRC

The number of trips per year required to transfer the material shown in Table 2.4 (and the other materials) to the HWRC site is 180,343 trips. This is for all materials taken to the site (see Table B6 in the Appendix for a detailed breakdown). The energy associated with this number of trips is then calculated in the same manner as in section 2.2.1.2 (using the same constants for distance to site and fuel consumption). This gives the total energy consumption for transportation of all material to the site. The energy consumption associated with the transfer of the different metals to the HWRC is then calculated by multiplying the total consumption by the proportion of each metals type taken to the site per trip, as given in Table 2.4. This gives a total annual energy consumption for the metals fraction of 1722.0 GJ, which breaks down in to the following for the different sub-categories of the metals waste fraction:

a) Mixed metals can bank – 2.5 GJ
b) Metals skip – 1360.7 GJ
c) White goods – 302.4 GJ
d) Batteries – 56.5 GJ

2.5.2 Stage 2 Transport

Transfer of the metals from the bring-sites and HWRC to the next stage of the recycling chain/cycle is dependent upon the collection facility, and these are described in more detail here.

2.5.2.1 Mixed Metals Can Bank

Transfer from these banks, either at the bring-sites or the HWRC, is assumed to be direct to the MDR-MRF. For the bring-site banks the return-journey distance is 49.08 miles (determined by a route planner), with 69 collections per year from the bring-sites for the base-case scenario [28]. For the can bank located at the HWRC, the return-journey distance is 38 miles (determined by a route planner), with an assumed number of collections of 12 per year from the HWRC for the base-case scenario.

In both cases, the default value of 20 minutes is used for the loading/unloading time of the skip lorry used to transfer the banks to the MDR-MRF. This gives an energy consumption per collection for the base-case scenario of 1335 MJ for the bring-sites, and 1052 MJ for the HWRC site. Annually, this equates to total energy consumptions of 92.1 GJ and 12.6 GJ, respectively.

2.5.2.2 HWRC Mixed Metals Skip

Transfer of the mixed metals is to a scrap merchant, assumed to be located 50 miles from the HWRC site. The average number of collections per year from the HWRC is estimated as 178, taken from data supplied by Southampton City Council [3]. Transfer to the scrap merchant is by a Ro-Ro truck.

The energy consumption per trip, determined in the same manner as described in section 2.3.2.2, is calculated as 2638 MJ per collection for the base-case scenario, giving an annual energy consumption of 469.6 GJ.

2.5.2.3 HWRC White Goods

Transfer of white goods is also presently assumed to be to the scrap merchant located 50 miles from the HWRC, with an assumed number of collections per year of 12. The energy consumption per trip is the same as calculated in section 2.5.2.2, giving an annual consumption of 31.7 GJ, for the base-case scenario.

2.5.2.4 HWRC Batteries

Transfer of batteries is, as for the white goods, presently assumed to be to the scrap merchant located 50 miles from the HWRC, with an assumed number of collections per year of 12. The energy consumption per trip is the same as calculated in section 2.5.2.2, also giving a total annual consumption of 31.7 GJ, for the base-case scenario.

It should be noted that the exact transfer route and recycling procedure for the mixed metals, white goods and batteries is not clearly defined in the present model, and this will be addressed in future developments of the model. In particular, the model presently only transfers the white goods and batteries to the scrap merchant, and goes no further. Hence, it only examines the effect that recycling of the other metals sub-categories has on the energy consumption associated with the disposal/recycling/processing of the metals fraction.

2.5.3 Kerbside Collection

As with the plastics fraction, the model presently only considers kerbside collection via the dry recyclables scheme. In the future the model will also include the option for the separate kerbside collection of source segregated metals (mixed metals cans only), or mixtures of other dry recyclables; for instance, mixed metal cans together with glass.

The dry recyclables scheme only collects ferrous and aluminium food and beverage cans, and it is the energy consumption associated with these materials that is calculated in the same manner as for the other materials collected by the dry recyclables scheme.

2.5.4 MDR-MRF

The method for determination of the energy consumption associated with the separation of the mixed metals cans at the MDR-MRF is the same as for the paper/card fraction (section 2.3.4). The only difference in the calculations is the destination of the metals leaving the MRF, details of which are given in Table C1.

2.5.5 Stage 3 Transport

This is transfer of the collected material to the next stage of the recycling chain/cycle. For the metals fraction this is transfer from the WTS to the MDR-MRF (dry recyclables); from the MDR-MRF to the metals processing facility (dry recyclables and metals can banks); and from the scrap merchant to the metals processing facility (metals skip). As mentioned, the model does not presently consider transfer of white goods or batteries from the scrap yard to appropriate processing facilities.

Transfer of the dry recyclables from the WTS to the MDR-MRF is detailed in section 2.3.5. Details of the distances travelled and truck sizes for transfer from the MDR-MRF to the metals processing facilities are given in Table C1. Using these input parameters gives energy consumption values per trip of 9.55 GJ for transfer of ferrous cans, and 11.49 GJ for transfer of aluminium cans. This gives 13.13 GJ and 5.64 GJ annually, respectively, for the base-case scenario.

Transfer of material from the scrap merchant to the metals processing facilities is using the same size trucks as given in Table C1, for the appropriate metals. Only transfer to a ferrous and an aluminium processing facility are presently considered. Also, the model presently assumes that all ferrous metal is iron and all non-ferrous metal is aluminium. This is because the breakdown of the different metal types within the metals skip is not presently known, although future model developments will address this issue.

The distance to the ferrous and aluminium processing facilities are 119.3 and 157.3 miles, respectively. These distances are calculated from a route planner, assuming that the scrap merchant is located north of Southampton and on the route from the MDR-MRF to the metals processing facilities, whose distances are given in Table C1.

Using these input parameters gives energy consumption values per trip of 6.18 GJ for transfer of the ferrous material and 8.13 GJ for transfer of the aluminium material. This gives 233.6 GJ and 43.0 GJ annually, respectively, for the base-case scenario.

2.5.6 Scrap Merchant

This is a simple sub-model that only considers the scrap merchant to be a sorting facility that separates the metals fraction into the different types of metal. It presently assumes that there is no energy consumption associated with the sorting of the metals, since this has not yet been investigated.

It has also been assumed that a loss of five percent is associated with the sorting process. Furthermore, it is assumed that this material is sent to a landfill site for disposal. This site is assumed to be located 50 miles from the scrap merchant, and the material is transferred using a 10 tonne capacity truck. The energy consumption associated with this transfer is 2.64 GJ per trip, equating to an annual energy consumption of 11.1 GJ for the base-case scenario.

2.5.7 Metals Manufacture/Processing

The model presently only considers processing of tinplate, iron and aluminium, since data is limited for other metals and/or the composition of the metals skip is not known. Future developments of the model will, however, include processing of other materials.

2.5.7.1 Tinplate Processing/Production

The model assumes that all ferrous metal cans collected via the mixed metals can banks and dry recyclables scheme are tinplate, i.e. steel coated with tin in order to prevent rusting.

The amount of metal cans used in Southampton annually is estimated at 1873 tonnes, based on the amount of material recycled and the amount in the refuse (Table B1), for the base-case scenario. The amount of metal cans recycled is determined from the amount of metals recycled via the mixed metals can banks (base-case level), and the assumption that the

percentage split of the different types of metals recycled (ferrous and non-ferrous cans) is the same as the split of these type of metals in the refuse (see Table B3).
The energy consumption associated with the production of one tonne of virgin tinplate is 35.77 GJ [37], whereas for recycled tinplate it is 17.18 GJ [37]. For the production of tinplate from recycled material it has been assumed that a loss of 6.6 % is incurred during processing of the recovered tinplate [37].
From this, the proportion of recycled and virgin material required to produce 1873 tonnes per year of tinplate can be determined for different material recycling rates. For the base-case scenario the proportion is approximately 1.4 % recycled material (25.7 tonnes/year after losses), and 98.6 % virgin material.
The energy consumption required to produce the tinplate is then calculated separately for the virgin and recycled tinplate and then summed to give the total annual energy consumption of approximately 66525 GJ (35.52 GJ/tonne tinplate produced). This includes the energy associated with the transport of the waste material associated with the losses during processing of the recycled material. It is assumed that this material is sent to landfill, using a 20 tonne truck travelling a round-trip distance of 30 miles. The annual energy consumption for this transfer (for the base-case scenario) is 0.08 GJ.

2.5.7.2 Iron Processing/Production

The model assumes that all the ferrous metals from the metals skip is iron, as indicated in section 2.5.6, and in this section 'iron' will be taken to mean 'ferrous metals'.
The amount of iron used in Southampton annually is estimated at 1510 tonnes, based on the amount of material recycled and the amount in the refuse (Table B1) for the base-case scenario. The amount of iron recycled is determined from the amount of metals recycled via the HWRC metals skip (base-case level), and the assumption that the percentage split of the different types of metals recycled ('Other ferrous' and 'Other' - non-ferrous – sub-categories) is the same as the split of these type of metals in the refuse (see Table B3).
The energy consumption associated with the production of one tonne of virgin iron is 7.92 GJ [37], whereas for recycled iron it is 1.8 GJ [37]. For the production of iron from recycled material it has been assumed that a loss of 6.6 % is incurred during processing of the recovered iron [37].
From this, the proportion of recycled and virgin material required to produce 1509 tonnes per year of iron can be determined for different material recycling rates. For the base-case scenario the proportion is approximately 46.7 % recycled material (705.5 tonnes/year after losses), and 53.3 % virgin material.
The energy consumption required to produce the iron is then calculated separately for the virgin and recycled iron and then summed to give the total annual energy consumption of approximately 7642 GJ (5.06 GJ/tonne iron produced). This includes the energy associated with the transport of the waste material associated with the losses during processing of the recycled material, which is calculated as approximately 2.1 GJ/year (for the base-case scenario).

2.5.7.3 Aluminium Processing/Production

The model assumes that all the non-ferrous metals from the metals skip is aluminium, as indicated in section 2.5.6, and in this section 'aluminium' will be taken to mean 'non-ferrous metals'. As mentioned, when more data becomes available, processing of other metals such as copper will be included in the model.
The amount of aluminium used in Southampton annually is estimated at 876 tonnes, based on the amount of material recycled and the amount in the refuse (Table B1), for the base-case scenario. The amount of aluminium recycled is determined from the amount of metals

recycled via the mixed metals can banks and HWRC metals skip (base-case level), and the assumption that the percentage split of the different types of metals recycled via each collection facility is the same as the split of these type of metals in the refuse (see Table B3).
The energy consumption associated with the production of one tonne of virgin aluminium is 182.80 GJ [37], whereas for recycled aluminium it is 8.24 GJ [37]. For the production of aluminium from recycled material it has been assumed that a loss of 5 % is incurred during processing of the recovered aluminium [37].
From this, the proportion of recycled and virgin material required to produce 876 tonnes per year of aluminium can be determined for different material recycling rates. For the base-case scenario the proportion is approximately 5.0 % recycled material (43.9 tonnes/year after losses), 95 % virgin material.
The energy consumption required to produce the aluminium is then calculated separately for the virgin and recycled aluminium and summed to give the total annual energy consumption of approximately 152,528 GJ (174.05 GJ/tonne aluminium produced). This includes the energy associated with the transport of the waste material associated with the losses during processing of the recycled material, which is calculated as approximately 0.1 GJ/year (for the base-case scenario).

2.5.8 Refuse Collection

The energy consumption associated with the transfer of the refuse from the household to the WTS is ~ 547 MJ per individual refuse collection, equating to ~171 GJ/year for transfer of the metals fraction only.

2.5.9 Landfill Transfer

The landfill transfer sub-model for the metals model is the same as the sub-model used for glass (section 2.2.8). Using the same methodology, the annual energy consumption figure associated with the metals fraction of the refuse is ~151 GJ/year.

2.5.10 Incineration

For details of the incineration sub-model refer to section 2.2.9.

2.6 ORGANICS FRACTION

For the organics waste fraction the following sub-models are employed:

1. Stage 1 transport (household to HWRC)
2. Stage 2 transport (HWRC to compost site/wood processor)
3. Kerbside Collection (Garden Waste, Food Waste, Organics Waste)
4. Composting (Centralised and Home)
5. Anaerobic Digestion
6. Refuse collection
7. Landfill transfer
8. Incineration

Most of these sub-models are similar to those used for the other waste fractions. There are, however, some new sub-models (e.g. Composting and Anaerobic Digestion).

HWRC Garden Waste skip:
PUTRESCIBLE:
Garden Waste

HWRC Wood Skip:
MISC. COMBUSTIBLE:
Wood

Refuse:
MISC. COMBUSTIBLE:
Wood
PUTRESCIBLE:
Garden Waste
Kitchen compostable
Kitchen non-compostable

Kerbside Garden Waste Scheme:
PUTRESCIBLE:
Garden Waste

Kerbside Kitchen Waste Scheme:
PUTRESCIBLE:
Kitchen compostable
Kitchen non-compostable

Kerbside Organics Waste Scheme:
PUTRESCIBLE:
Garden Waste
Kitchen compostable
Kitchen non-compostable

Figure 2.17: Distribution of Organics Sub-Categories amongst Collection Systems

The distribution amongst the various possible collection systems is shown in Figure 2.17 (excluding home composting), and the waste management structure for organics (base-case scenario only) is given in Figure 2.18 (only shows options presently considered by the model).

For the classification system used in the model (Table B3), the organics fraction can be found in two different categories of waste:

Misc. combustible (5) (3.26 %):
Wood (5.04) (15.16 %[4]; 3.26 %)

Putrescible (10) (96.74 %):
Garden Waste (10.01) (53.19 %; 51.46 %)
Kitchen compostable (10.02) (31.26; 30.24 %)
Kitchen non-compostable (10.03) (15.55; 15.04 %)
Unclassified (10.04) (0.00 %; 0.00 %)

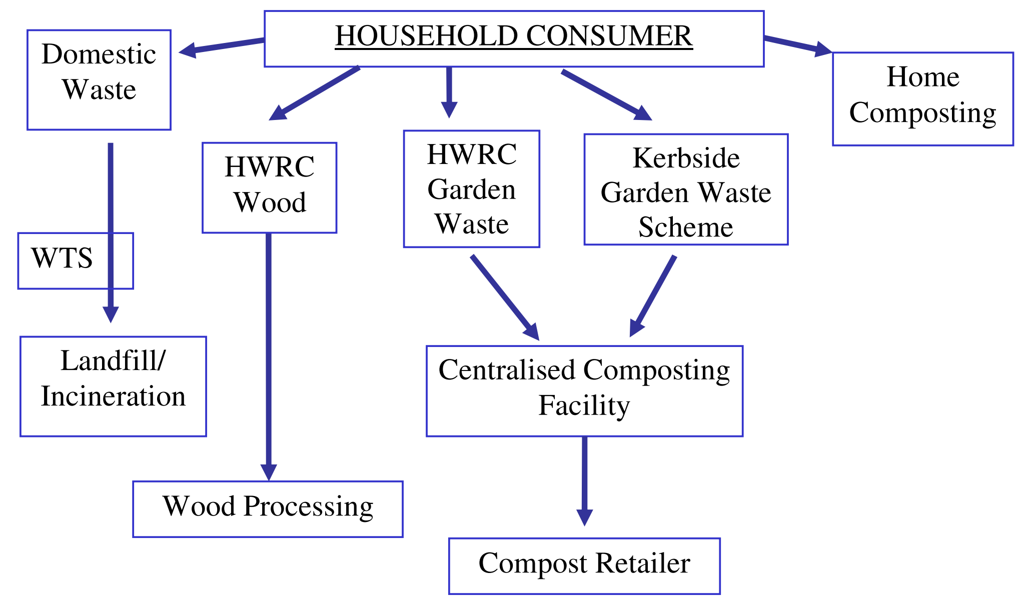


Figure 2.18: Organics Waste Management Scheme

2.6.1 Stage 1 Transport

Only recycling via the HWRC site is considered in here, since there are no bring-sites collection facilities for organic material in Southampton, although the model can be adapted to examine such a scenario. There are two collection facilities for organics located at the HWRC: garden waste and wood. The sub-categories of materials collected via each facility are given in Figure 2.17.

The amount of garden waste taken to the HWRC annually is estimated as 1239 tonnes (9.6 % recycling rate) [12], whereas for wood it is 137 tonnes (16.9 % recycling rate) [3]. The model presently assumes that all wood material is untreated and is, therefore, recyclable.

As with the other waste fractions it is assumed that the amount of material taken to the HWRC site per trip is a fraction of the total amount taken (20 kg), based on the percentage of

[4] The 'misc. combustible' category contains other materials that are not defined as organics (e.g. nappies). Hence, the value given here represents the amount of wood as a percentage of the total amount of material within this category.

each material found at the site. For garden waste the percentage is 34.3 %, whereas for wood it is 3.8 % (see Table B6 for more details). As mentioned in section 2.5.1.2 the model may be changed in order to take into account the fact that relatively large amounts of certain material may be taken to the HWRC in a single trip. This may be true for garden waste, where the amount is likely to be disproportionate to the percentage of each material found at the site (see Table B6).

The energy consumption associated with the transfer of the different organics material to the HWRC is then calculated by multiplying the total consumption by the proportion of each organics type taken to the site per trip, which gives annual energy consumption figures of ~2007 GJ for garden waste, and ~222 GJ for wood (Table B6).

2.6.2 Stage 2 Transport

This is transfer of material from the HWRC to a compost facility (garden waste) and to a wood processor (wood).

Transfer of the garden waste is to a local compost facility. This is presently assumed to be the facility located at Down End Quarry, although it is intended that future development of the model will allow transfer of material to more than one facility. The distance to the compost facility, as determined from a route planner, is 13.3 miles and the annual number of collections from the HWRC is 231, determined from data supplied by Hampshire County Council [12]. This gives an energy consumption per trip of 760 MJ, corresponding to a total of ~176 GJ/year for the base-case scenario.

Transfer of the wood from the HWRC is assumed to be to a processor located 50 miles away, with 47 collections per year [3]. This part of the organics model has not yet been fully developed, and will be expanded in the future. By using the above parameters, however, the energy consumption per trip is calculated to be 2.64 GJ, giving an annual energy consumption of ~123 GJ for the base-case scenario.

2.6.3 Kerbside Collection

Three different kerbside collection schemes are included in the organics model: garden waste, food (kitchen) waste, and organics (garden + food) waste. Only the garden waste collection scheme is, however, considered in the present model, although future development of the model will examine the other schemes.

2.6.3.1 Garden Waste Scheme

Southampton City Council introduced a trial kerbside collection scheme for garden waste in June 2001. This provided collection of the garden waste from 2376 households (after the phasing-in of the trial had been completed). This represents ~ 2.6 % of all households in Southampton, and ~4.1 % of all households deemed 'Detached', 'Semi-Detached' and 'Terraced', i.e. only those housing types that are likely to have gardens. The scheme was, however, discontinued in October 2003, when it was replaced by a city-wide opt-in (pay) scheme.

Data supplied by Southampton City Council [3, 28] for the period June 2001 – March 2003 shows that an average of 304.52 tonnes per year were collected in the trial area, which represents 2.37 % of the total amount of green waste available for recycling (12,865 tonnes/year).

The garden waste is taken direct to a compost facility, presently assumed to be the same facility as detailed in section 2.6.2, using a 3 tonne truck [28], and the average number of collections per year is 93 [3]. The distance to the compost facility is estimated to be 15 miles, using the same approach as detailed in section 2.2.7.

Calculation of the energy consumption is carried out in a similar manner to that described in section 2.3.3.1. From above, the proportion of households involved with the trial scheme is 2.6 %, located in discrete areas of the city. Hence, it is assumed that this also represents 2.6 % of the area of Southampton and, as such, this is equivalent to 2.6 % of the length of Southampton's roads (i.e. 354.8 miles).
As in section 2.3.3.1, the distance travelled per collection can be calculated (assuming a fortnightly collection frequency for the garden waste scheme). This gives an energy consumption of 866 MJ per collection, equivalent to an annual energy consumption of 80.5 GJ.

2.6.4 Composting

The model considers both centralised composting and home composting, and details of each are given here.

2.6.4.1 Centralised Composting

Presently, the model only considers the open-windrow technique of centralised composting, although it is anticipated that future developments of the model will examine other techniques, such as in-vessel composting.
EPA data for the period 2000 – 2002 from Hampshire County Council [12] indicates that approximately 22.7 % of the garden waste from the HWRC is rejected at (assumed) the compost facility. This figure is higher than normal because during part of this period the Down End facility was closed due to odour problems [38]. The model presently assumes that the reject material is sent to landfill for disposal, and this is discussed in more detail later in this section.
The compost sub-model is fairly simplistic at present, and does not yet include any energy consumption figures associated with the composting process and operation of the composting facility, including on-site mobile plant (including vehicles). Therefore, it only considers a mass balance of the facility itself, and transfer of material from the facility.
It is assumed [39] that 50 % of the input mass of garden waste is lost through moisture losses and respiration. Furthermore, it is assumed that 0.2 % of the input material [40] is outputted as waste (residue, generally contaminants). It is assumed that this waste material is sent for disposal at a landfill site, located 25 miles from the compost facility, using a 20 tonne truck. The annual energy consumption associated with this transfer is 1.36 GJ.
Transfer of the compost product itself is assumed to be to a local retailer located 25 miles from the compost site, using a 20 tonne capacity truck. The energy consumption associated with this transfer is estimated to be 1359 MJ per trip, giving an annual energy consumption of 43.48 GJ.
As mentioned earlier, the model sends the material rejected at the gate for disposal at a landfill site, and the model assumes that this is the same site where the waste material is sent. The reject material is, however, sent separately from the waste material since the model assumes that the vehicle transferring the garden waste material from the HWRC (and kerbside scheme) is simply sent away from the compost facility and on to the landfill site.
The energy consumption associated with the transfer of the reject material is also 1359 MJ per trip (same trip distance), giving an annual energy consumption of 73.37 GJ (for 54 trips per year, estimated from [12]).

2.6.4.2 Home Composting

The model presently assumes that no material is home composted in Southampton. Although this is not the case, the amounts are not known, and it will not affect the trends found when comparing the base-case scenario with other scenarios, since it is comparative. In the future

the model will be developed to include actual (or best estimates of) levels of home composting, and also possibly address the issue of burning of garden waste at home.
The home composting sub-model is simple, since the energy footprint model is presently only concerned with energy consumption. It is assumed that there is no inherent consumption of energy associated with home composting, and it only acts as a "sink" for diversion of garden waste material away from centralised composting facilities or disposal via landfill/incineration.

It should be noted that the model does not presently consider the affect of substitution of traditional compost products (i.e. peat-based compost) with compost material produced from garden waste, as is done for the other waste materials detailed in this report (glass, etc.). Further research needs to be carried out for this part of the model in order to examine this effect. In particular, it could be anticipated that the energy consumption associated with the transfer of traditional compost products to retail outlets in Hampshire is significantly higher than transfer of material produced at compost facilities located within Hampshire.

2.6.5 Anaerobic Digestion

The Anaerobic Digestion (AD) sub-model is under construction and examination of AD technologies or scenarios where AD of waste is employed are not presently considered. A sub-model is, however, being developed for a process that produces biogas from the anaerobic digestion of Food Waste, and uses a mass and energy balance for the process as detailed in [41].
This area of the model will be expanded as part of the second phase of the Energy Footprint project, where data will be used from research examining anaerobic digestion of organic waste that is being undertaken as part of the SUE Waste Consortium programme.

2.6.6 Refuse Collection

The energy consumption associated with the transfer of the refuse from the household to the WTS is ~ 547 MJ per individual refuse collection, equating to ~1116 GJ/year for transfer of the organics fraction only.

2.6.7 Landfill Transfer

The landfill transfer sub-model for the metals model is the same as the sub-model used for glass (section 2.2.8). Using the same methodology, the annual energy consumption figure associated with the organics fraction of the refuse is ~988 GJ/year.

2.6.8 Incineration

For details of the incineration sub-model refer to section 2.2.9.

3 RESULTS AND DISCUSSION

Here the results of different scenarios run for the different waste fractions separately and collectively are given. Comparison is also made between the different waste fractions in order to highlight which material, in terms of recycling, has the greatest/least impact on energy consumption and other parameters such as refuse composition.

3.1 GLASS FRACTION

This section highlights the effect that recycling has on the energy consumption for the different components associated with the waste management chain/cycle for the glass fraction. In addition, the effect that various parameters have on the energy consumption is also examined. This includes factors such as bring-site density, method of collection/recycling, transfer method, use of cullet, and the effect of incineration of the residual waste stream.

3.1.1 Energy Consumption of Waste Chain/Cycle Components

Figures 3.1 and 3.2 show the annual energy consumption values for the different stages of glass recycling and waste management, and how these vary with glass recycling rate. The energy consumption for the base-case scenario is indicated by the vertical dashed line (at 25.84 % recycling rate, equivalent to a recovery rate of 26.21 %). It should be noted that, as seen in the figures, the maximum achievable recycling rate is not 100 %, but only 98.6 % although this corresponds to a 100 % recovery rate. This is because the model assumes that the “Other Glass” (7.04) sub-category (see section 2.2) of the glass fraction within the refuse is not presently recyclable, since it represents broken and/or non-container glass.
The graphs show that the energy consumption for both stage 1 and stage 2 transportation increases with an increase in the recycling rate. This is because a fixed site density has been used; hence, the average distance to the bring-site remains fixed, but the number of trips made increases linearly as more glass is recycled. Clearly, in practice high recycling rates will not be achieved without increasing the site density and this will be discussed later. Similarly, for stage 2 transport, as the recycling rate increases so does the number of collections required to empty the bottle banks.

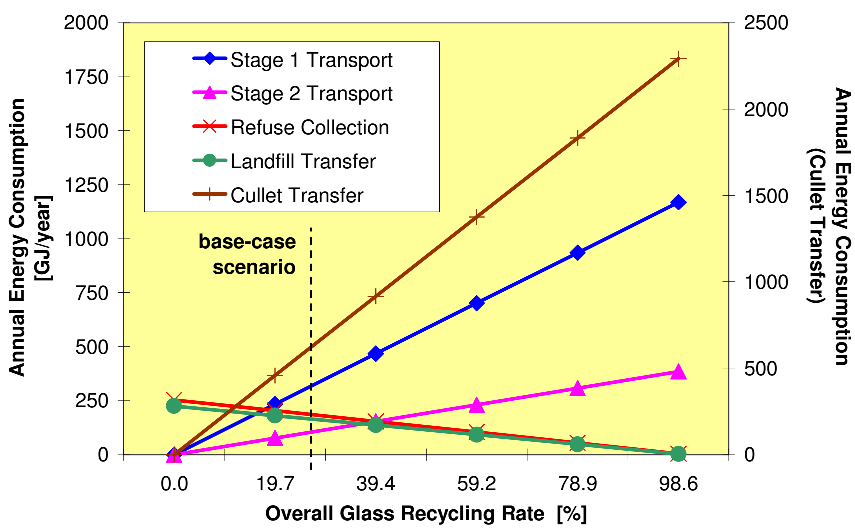


Figure 3.1: Effect of Glass Recycling Rate on Energy Consumption (minor components)

It can be seen from Figure 3.2 that the bulk of the energy consumed is in the manufacturing process. Of course, this would be expected since it is energy intensive, but it also shows the effect that recycling has on the amount of energy consumed, giving an 8.8 % decrease in consumption going from zero to maximum recycling (17 % and ~95 % cullet use in the glass furnace, respectively). Compared to the base-case level of recycling (25.84 %), the decrease is 6.6 % with maximum recycling.
Hence, the relatively large saving in manufacturing energy offsets any increases in energy consumption through increased transportation, even when the cullet has to be transported relatively large distances by ship.

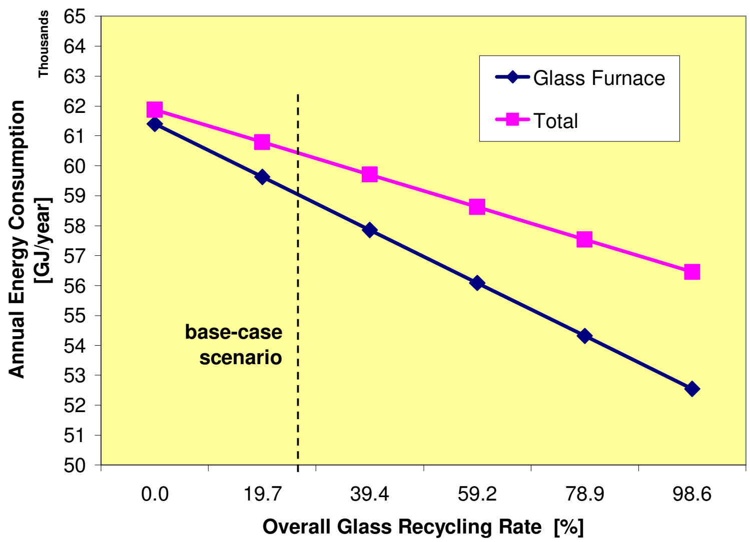


Figure 3.2: Effect of Glass Recycling Rate on Energy Consumption (major components)

Although not presently examined in the model it would also seem sensible, in order to eliminate the energy consumption required for transportation, to site a glass manufacturing plant adjacent to the processing plant at the Docks. This would remove the need to transfer the cullet long distances. One must not forget, however, that the raw materials also have to be shipped to the manufacturing plant although, of course, the need for raw materials can be reduced significantly through increased recycling. Naturally, the siting of a glass manufacturing plant would be subject to a whole range of economic, social and environmental considerations. Account of the relevant issues is best achieved through an environmental impact assessment, which is beyond the scope of this project.

3.1.2 Bring-Site Density

A practical measure that can be taken in order to encourage recycling would be to increase the site density, or number of bottle banks located within the city. This should make it easier (more convenient) for people to recycle. In order to model this scenario it has been assumed that at a recycling rate of 0 % the number of sites is 0; for the base-case level of recycling (25.84 %) the value is 3.954 sites per 10.000 inhabitants (86 sites in Southampton), and for maximum recycling a value of 15 sites per 10.000 (326 in Southampton) has been used [6]. The straight-line equation determined from these points is as follows:

$$\text{Site density} = (0.152 \times \text{recycling rate}) + 0.0105 \qquad \textbf{(10)}$$

From this, the site density for any given recycling rate can be determined, and Figure 3.3 shows the collection energy consumption (stages 1 and 2 transport) for the transfer from the household to the processing plant via the bottle banks for this variable site density. The graph also shows the energy consumption for a fixed site density (3.954 sites per 10,000 inhabitants).

The results show that the collection energy consumption is less for a variable site density than it is for a fixed density, since the energy consumption for transporting the glass from the household to the bring-site (stage 1 transport) is less once the recycling rate increases above the base-case level (25.84 %). This is because, as the site density is increased the average distance to a site decreases, resulting in not only a decrease in the amount of fuel consumed per trip, but also in the number of trips made specifically for recycling, with more people travelling by foot. For instance, for the base-case scenario the distance travelled to the bring-sites is approximately 0.13 miles, and the percentage of trips made specifically for recycling is 27.8 %. For a site density of 15 the distance travelled is, however, only ~ 0.07 miles, and the percentage of trips reduces to 18.4 %.

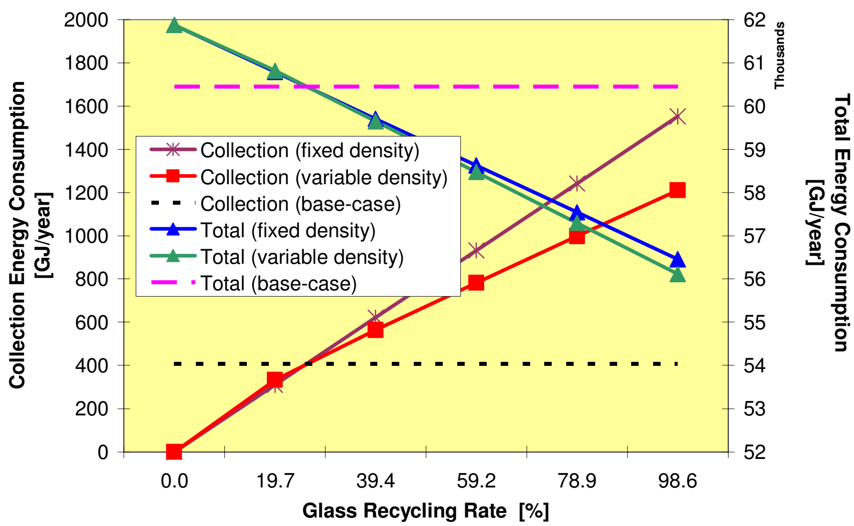


Figure 3.3: Effect of Bottle Bank Site Density on Energy Consumption

Although the stage 1 transport energy is less for a variable site density, the energy consumed during stage 2 transport (bottle banks to processing plant) will remain fixed, since it is independent of the site density. This is because although an increase in the number of bottle banks will mean that more banks will need to be emptied they will, however, not need to be emptied so frequently. The opposite will also be true for a decrease in the number of bottle banks. Hence, the energy consumption will remain constant, for a given amount of glass recycle (assuming the bottle banks are only emptied when full).

The graph also shows that because of the reduction in collection energy, the total energy consumption is also slightly less for the variable site density scenario than for the fixed density scenario. But, the savings at the maximum recycling rate are only 0.6 %, which is not significant. What is more important is the fact that the energy consumption decreases with an increase in recycling rate. Thus, if increasing the site density leads to an increase in the recycling rate then it will be beneficial. This does, however, assume that a particular recycling rate will be achievable for a given site density, according to equation (10). Also, it would be expected that increasing the number of sites would increase recycling, since more people are likely to recycle if the nearest bottle bank is closer particularly if it is within walking distance.

Public awareness and education are also important in order to change people's attitudes and encourage them to recycle. Indeed, if public awareness can be raised then it might be possible to achieve an increase in the recycling rate without necessarily increasing the site density. This would be beneficial since it would not require such a large increase in the recycling infrastructure associated with an increase in site density. Indeed, although having more bottle banks does not increase the collection energy consumption, it does require the actual manufacture of more bottle banks. Although this is not examined in the present model, there will be an energy consumption associated with this manufacture and if this is taken into account then the trend or magnitude of difference in the energy consumption as seen above may be somewhat different.

3.1.3 Location of Bottle Banks

One issue related to recycling at Household Waste Recycling Centres is what recycling facilities should actually be located there. For instance, do bottle banks at HWRCs encourage people to recycle other materials there?; or are there people who only recycle glass at the HWRC and who could contribute to peak-time congestion problems, thus deterring other people from using the other recycling facilities at the HWRC?

Although the scope of the Energy Footprint project does not address these issues, it does examine the effect of recycling via bring-sites and HWRC sites in terms of energy consumption. For the base-case scenario, 1271 tonnes per year are recycled via 86 bring-sites located throughout Southampton. This is equivalent to an average of ~ 14.8 tonnes per bring-site, compared to 105.1 tonnes collected via the HWRC site located at Endle Street. Hence, approximately seven times more glass is recycled at the HWRC than at the individual bring-sites. Thus, on a weight-basis, recycling via the HWRC is more "efficient" than bring-sites.

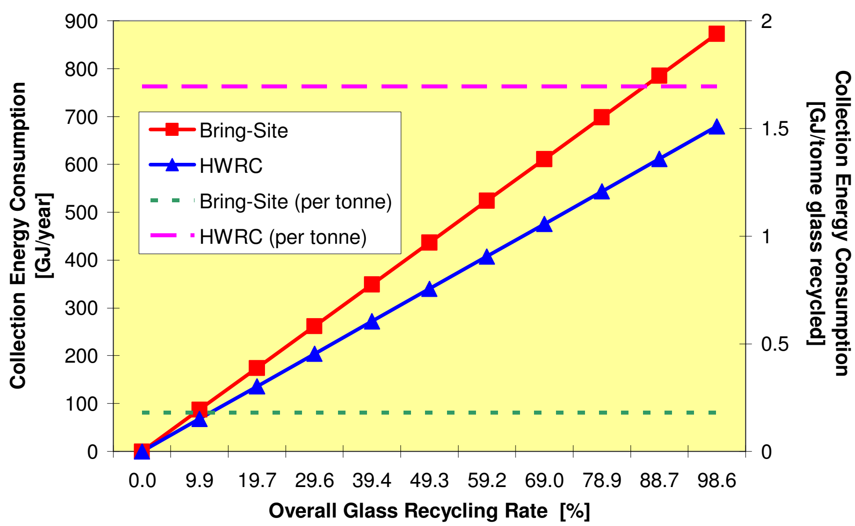


Figure 3.4: Comparison of Energy Consumption for Transport to Bring Sites and to a HWRC Site (Glass Fraction)

Does the HWRC, however, show such efficiency in terms of energy consumption? Figure 3.4 compares the energy consumption for transfer of glass from the household to the processing plant via bring-sites and the HWRC site (sum of stage 1 and stage 2 transport stages for both). The graph shows that the transport energy for transfer of the glass via the bring-sites is greater than for the HWRC site, although at the maximum recycling rate it is only ~ 1.3 times greater. Furthermore, this is the total transport energy for all the bring-sites: if the energy consumption is expressed in terms of GJ per tonne of glass collected, then the trend is reversed. For the HWRC the energy consumption is 1.695 GJ/tonne glass collected, whereas it is only 0.18 GJ/tonne for the bring-sites, which is approximately a factor of nine less.

Hence, although more glass is recycled at the HWRC site than at individual bring-sites, more energy is required per tonne to transfer the glass via the HWRC site. The reason for this is two-fold: firstly, the model assumes that all journeys to the HWRC site are for recycling purposes only, whereas for bring-sites it is significantly less (27.8 % for the base-case scenario); secondly, the average distance to the HWRC is 2.5 miles, compared to only ~ 0.13 miles to the bring-sites. Hence, the effect is to increase the transfer-miles per tonne of material recycled via the HWRC site. This is discussed in more detail in section 3.6.2.

On this basis it would seem more appropriate, in terms of energy consumption, not to locate a bottle bank at the HWRC site. As shown above, however, more glass is recycled proportionately here than at individual bring-sites. Hence, removing the bank from the HWRC could lead to a reduction in the total amount of glass recycled. For instance, for the base-case scenario removing the bottle bank at the HWRC could reduce the amount recycled by a maximum of 105.1 tonnes, reducing the recycling rate from 25.84 % to 23.87 %. But, would this reduction in the amount of glass recycled also reduce the total energy consumption associated with the glass waste chain/cycle?

This is examined in Figure 3.5, which shows the effect that removing the bottle bank from the HWRC has on transport energy and total energy consumption. The x-axis represents the progressive addition to the bring-sites of the glass "removed" from the HWRC, for the base-case level scenario of recycling via bring-sites (1271 tonnes collected). The value of 14.8 tonnes is the total amount of extra glass expected to be collected at the bring-sites (172 kg per site) if the HWRC bottle bank is removed. This value is used because, as previously mentioned, approximately seven times less (14.8 tonnes) glass is collected per bring-site than at the HWRC (105.1 tonnes for the base-case scenario). That is, when the HWRC bottle bank is removed the recycled glass will be re-distributed amongst the bring-sites, but it is assumed that there will be a seven-fold decrease in the amount collected (re-distributed).

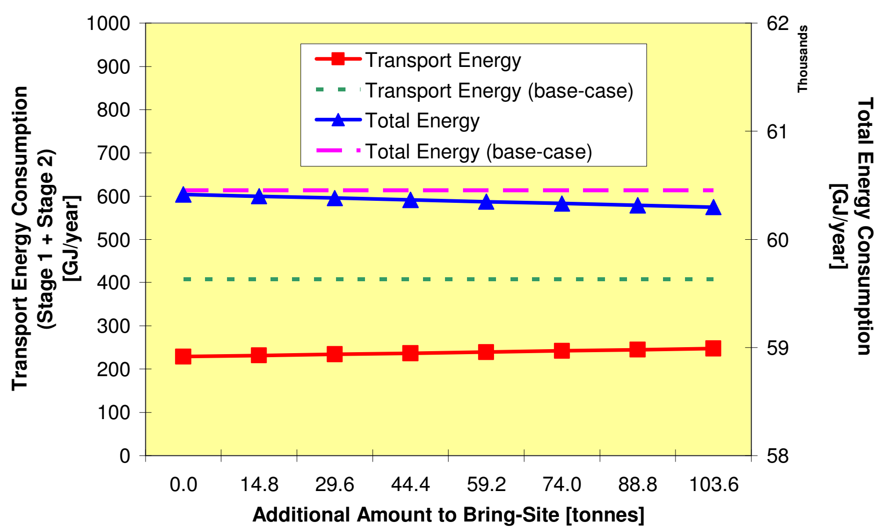


Figure 3.5: Effect of removing Bottle Bank from HWRC Site

The graph shows that, compared to the base-case scenario, the transport energy consumption is less for recycling via bring-sites only (rather than a combination of bring-sites and HWRC). Also, with no extra glass from the HWRC there is a slight decrease in the total energy consumption when compared to the base-case scenario. This is because the reduction in transport energy consumption is enough to offset the increase in the manufacturing energy consumption due to a decrease in the amount of recycled glass used in the manufacturing process (105.1 tonnes less). As the amount of extra glass collected at the bring-sites is increased, the transport energy increases (more glass collected), but it is still less than the base-case scenario. In addition, the manufacturing energy consumption decreases, which offsets the increase in transport energy, resulting in a decrease in the total energy consumption with an increase in extra glass collected.

Hence, the removal of glass recycling facilities from the HWRC site would not be detrimental in terms of energy consumption, even if no extra glass was collected via bring-sites to compensate for removal of the HWRC bottle bank. Removal of the bottle bank would, however, have to be tempered against any possible detrimental effects on the overall amount of glass collected, or the amount of materials collected at the other recycling facilities located at the HWRC site.

3.1.4 Kerbside Collection

Another option to increase recycling would be to introduce a kerbside collection scheme to compliment or, largely, replace bottle banks. Switching to a 100% kerbside collection scheme (described in section 2.2.3) shows a significant decrease in energy consumption for the collection stage of glass recycling (Figure 3.6). For example, there is a reduction of ~ 69 % at the maximum recycling rate (98.59 %), when compared to the collection energy consumption for recycling (at the same rate) via bottle banks The reason for this reduction is because the need for householders to make a relatively large number of journeys to bottle banks, and subsequent transfer of the glass from these banks, has been removed. Instead, a 10 tonne capacity truck is used to collect the glass from the households, which is a far more efficient process. Indeed, the distance travelled to take the glass from the households to the processing plant via bottle banks is approximately 359,000 miles (return-journey distance) per year, for the base-case scenario. This compares to only approximately 10,700 miles for kerbside collection at the same recycling rate, which is a factor of more than 33 times less.

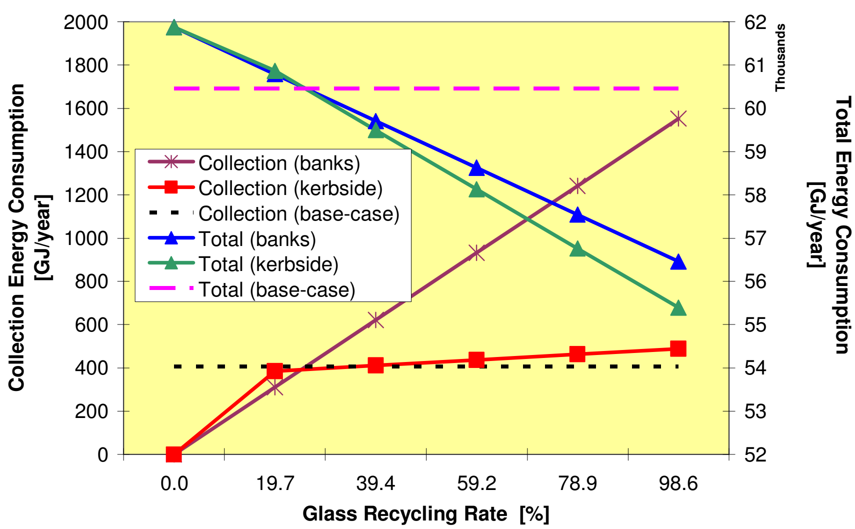


Figure 3.6: Effect of Kerbside Collection Scheme on Energy Consumption (Glass Fraction)

The use of a kerbside collection scheme to recycle glass not only reduces the initial collection (transfer) energy consumption but also the total energy consumption, as is also shown in Figure 3.6. Indeed, the maximum savings in energy is 8.4 % when compared to the base-case scenario energy consumption. This compares to only 6.6 % for maximum recycling via bottle banks.

In practice, however, even with a kerbside collection scheme covering the whole of the city, there would still be the requirement for some bottle bank sites to cope with periods of excess glass waste production (Christmas, etc.), especially with a fortnightly kerbside collection of glass. Hence, the savings in energy consumption would be somewhat less than the figure quoted above. The kerbside collection scheme would still be preferable though, especially since, by its very nature, a kerbside scheme would have a relatively high recycling rate [42], something not so readily achievable with recycling via bottle banks.

Figure 3.7 looks at the effect of a progressive introduction of a kerbside collection scheme for glass throughout the city. For this scenario it is assumed that households in those areas that are covered by the kerbside scheme do not use the bottle banks for any recycling. Conversely, those areas not covered by the scheme continue to use the bottle banks, and it is assumed that the site density for these areas remains fixed at the default value of 3.954 per 10,000 inhabitants.

The recovery rate in Figure 3.7 is assumed to be the same for both the kerbside collection scheme and recycling via bottle banks. Here, the recovery rate is defined as the ratio of the amount of glass collected (recycled) to the amount of glass available for recycling, and is effectively the product of the participation and capture (set-out) rates. The participation rate is the proportion of households who participate in the kerbside scheme, or use the bottle banks; whereas the capture rate is the proportion of material (glass) available that is set out by a household, or taken to the bottle banks. Hence, the recovery rate effectively indicates what proportion of material that can be recycled actually is recycled.

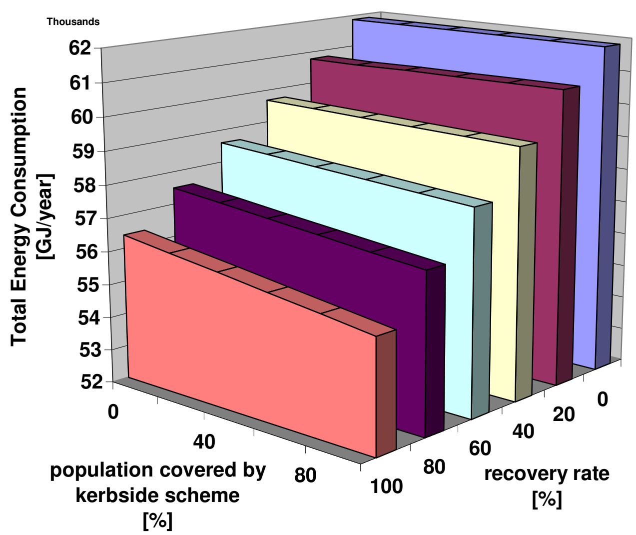


Figure 3.7: Effect of Introduction of a Kerbside Collection Scheme (variable bottle bank recovery rate)

The amount of material available for recycling, however, only includes the material that can be recycled. For instance, as mentioned earlier, it does not include the sub-category ‘Other

Glass' for the glass fraction, since this cannot be recycled. Therefore, it takes into account technology and infrastructure limitations with regard to what can be recycled. For instance, dense plastic food packaging is not presently collected for recycling in Southampton because the sorting facilities are not currently capable of sorting such material. The model, however, can be adapted and expanded to allow evaluation of the recycling of such material.

It is assumed that the amount available for recycling in the areas covered by the different collection methods is determined by:

$$\text{amount of material} = \text{total amount available} \times C \qquad (\mathbf{11})$$

where, C is the percentage of the population covered by the collection method (kerbside or bottle banks).

The annual energy consumption for each combination of kerbside coverage and glass recovery rate can then be determined. The results show, firstly, that the energy consumption decreases as the recovery rate increases, simply because as more glass is recycled, less energy is required for glass manufacture. Secondly, the total energy consumption also decreases with an increase in kerbside coverage. This decrease is minimal at a low recovery rate, but steadily increases to a maximum for a 100 % recovery rate (at 100 % kerbside coverage, as previously shown in Figure 3.6).

Although the graph shows that the energy consumption, compared to recycling via bottle banks only, is less for scenarios with high recovery rates and kerbside coverage, it is unlikely that such high recovery rates would be achievable in those areas using bottle banks only. Hence, a more realistic scenario has been modelled, which is shown in Figure 3.8. Here, the recovery rate for collection via bottle banks is kept fixed at 26.21 % (equivalent to a recycling rate of 25.84 %), which is the base-case scenario level. As before, the level of kerbside coverage is then varied, combined with variation in the recovery rate of glass collected from the kerbside.

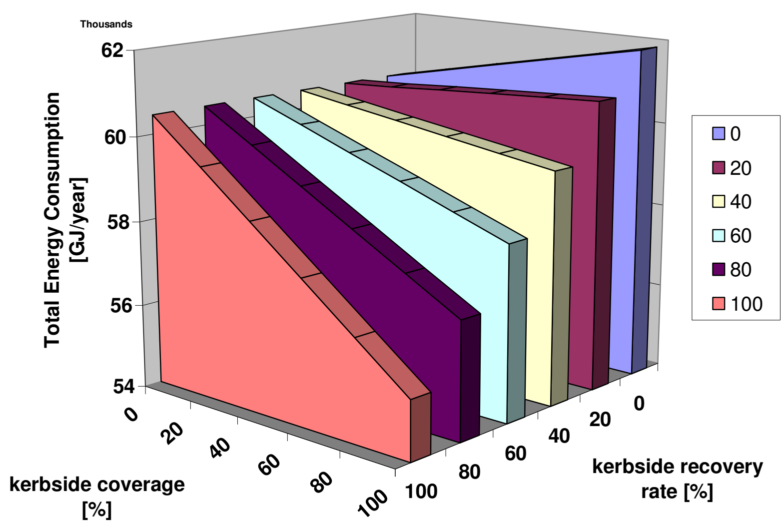


Figure 3.8: Effect of Introduction of a Kerbside Collection Scheme (fixed bottle bank recovery rate)

The results show that at low kerbside recovery rates the total energy consumption increases as the level of kerbside coverage is increased. Conversely, at higher recovery rates, the total consumption decreases with an increase in coverage. As with the scenario of kerbside recycling versus recycling via bottle banks (variable recovery), the minimum energy consumption is achieved at 100 % kerbside coverage with maximum kerbside recovery rate. Also, the variation in the energy consumption with recovery rate is not linear at a given level of coverage. This is because of the non-linear change in the overall glass recycling rate with kerbside coverage/recovery rate (Figure 3.9). For the base-case scenario (kerbside coverage = 0) the recycling rate is constant. Hence, at kerbside recovery rates lower than this base-case rate the overall recycling rate will decrease as the kerbside coverage is increased. For instance, at a kerbside recovery rate of 0 % the overall recycling rate decreases from 25.84 % (base-case banks level) to 0 % at 100 % kerbside coverage (no banks recycling). Conversely, when the kerbside recovery rate is greater than the fixed bottle bank rate the overall recycling rate increases progressively more sharply.

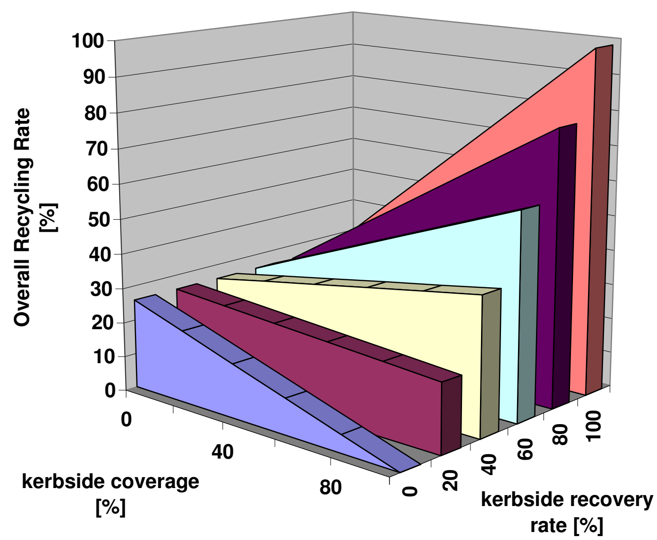


Figure 3.9: Effect of Kerbside Recovery Rate on Overall Recycling Rate

3.1.5 Incineration

Incineration is an option for waste management and is, therefore, considered for the glass waste chain/cycle. This is certainly true for the Southampton area, since a new waste incineration plant is due to come online in 2004. As glass is inert, however, its incineration actually consumes energy because it does not contribute to the energy produced, takes in heat, and would require landfilling/disposal after it has been incinerated. Hence, it would be expected that glass recycling would directly impact on the incineration of the residual waste, just as it impacts on refuse collection, landfill transfer, etc. Figure 3.10 shows the effect that incineration has on the energy consumption, and compares the following three scenarios:

1) recycling of the glass via bring-site/HWRC bottle banks with variable recycling rate, and landfill of the residual waste stream
2) no recycling of the glass, and variation of the level of incineration of the residual waste stream (with landfill of the remainder)
3) recycling via the bottle banks with a 100 % recovery rate and variable levels of incineration

The graph shows that compared to "recycling-plus-landfill", "no-recycling-plus-incineration" of the residual waste stream gives a much lower energy consumption, as would generally be expected. Indeed, at an incineration level of approximately 20 % the energy produced from incineration of the residual waste offsets the energy consumed from glass manufacture and other aspects of the glass waste chain/cycle. Above this level of incineration there is a net energy gain.

It should be noted here that the energy produced from incineration is based on a relatively high calorific value for the residual waste (see section 2.2.9). Hence, the magnitude will also be relatively high. Therefore, a lower, more representative, CV would give a lower energy value. This will not, however, affect the (relative) trends found here, since it will only shift the lines for incineration (both with and without recycling) upwards with the same magnitude. It will, however, effect the point where there is a net energy gain, shifting it towards the right (higher level of incineration).

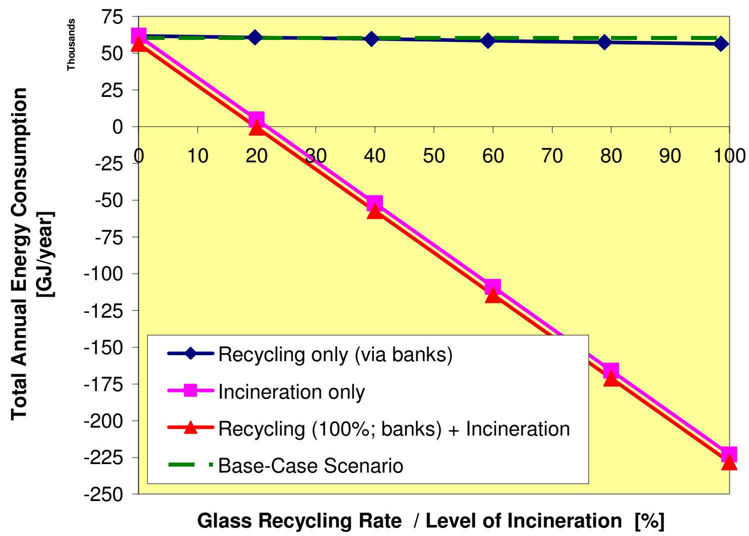


Figure 3.10: Effect of Incineration on Energy Consumption (Glass Fraction)

The results above suggest that, in terms of energy consumption, it would be better not to recycle glass and simply incinerate the residual waste stream. The graph also shows, however, that a combination of maximum recycling of glass combined with incineration of the residual waste "consumes" less energy than the "incineration-only" scenario. This is because, firstly, recycling reduces the energy consumption associated with the glass waste chain/cycle. Secondly, the effect that glass recycling has on incineration of the residual waste is not a detrimental one. This is because, although recycling reduces the amount of waste available for incineration, it increases the calorific value of the residual waste, as shown in Figure 3.11. Here, recycling increases the CV of the waste from ~ 16 MJ/kg at zero recycling to ~ 17.2 MJ/kg at maximum recycling, representing an approximately 7.3 % increase.

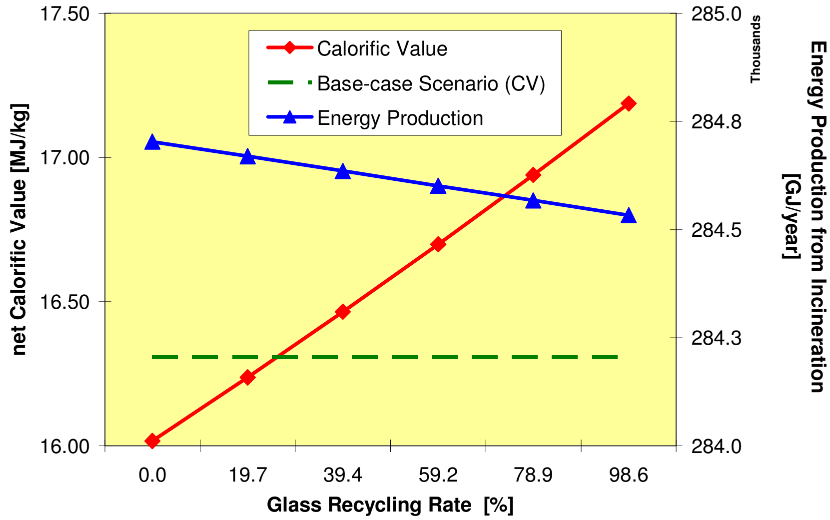


Figure 3.11: Effect of Recycling on Calorific Value of Residual Waste (Glass Fraction)

The decrease in the amount of refuse over the same range of recycling is, however, approximately 6.9 %. Thus, the combination of reduced amounts of waste and increased CV does not significantly affect the amount of energy produced from incineration at different levels of recycling. This is borne out by the right-hand axis of Figure 3.11, which shows how the amount of energy produced from incineration (100 % level of incineration of the residual waste stream) varies with level of recycling of the glass: the maximum difference is less than 0.1 %. Hence, it is only the energy consumption of the other waste management components for the glass fraction that are affected by recycling and, as shown, these decrease with an increase in recycling.

Therefore, because glass is inert it is better to remove it from the main waste stream, which may still be incinerated, and to recycle the glass to reduce the energy consumption from glass manufacture, since this combination gives the lowest level of energy consumption.

3.1.6 Cullet Transfer Mode

As mentioned in section 2.2.5 the glass recycling infrastructure for Southampton is somewhat unique because of the location of the processing plant at the Docks. This means that a large part of the journey to, ostensibly, the glass manufacturing plant can be made by sea rather than road. Does transfer of the cullet by ship and truck (transfer from the port), however, consume less energy than transfer by truck only?

This is examined in Figure 3.12, which compares the energy consumption for the two different transfer modes. For transfer of the cullet by road it is assumed that a 25 tonne capacity truck is used, and the transfer distance is 250 miles (one-way only). Transfer by ship is 438 miles (381 nautical miles), followed by a 75 mile (one-way only) truck journey (section 2.2.5).

The graph shows that the energy consumption for transfer by truck is less than by ship and truck: at maximum recycling the consumption is approximately 45 % less. The savings in transfer energy, however, equates to a reduction of only ~1.8 % in the total energy consumption. Hence, the option to switch to transfer by truck only in order to reduce the energy consumption should be tempered against other factors such as pollutant emissions, road congestion, etc. For instance, one ship load (1200 tonnes) is equivalent to 48 truck loads.

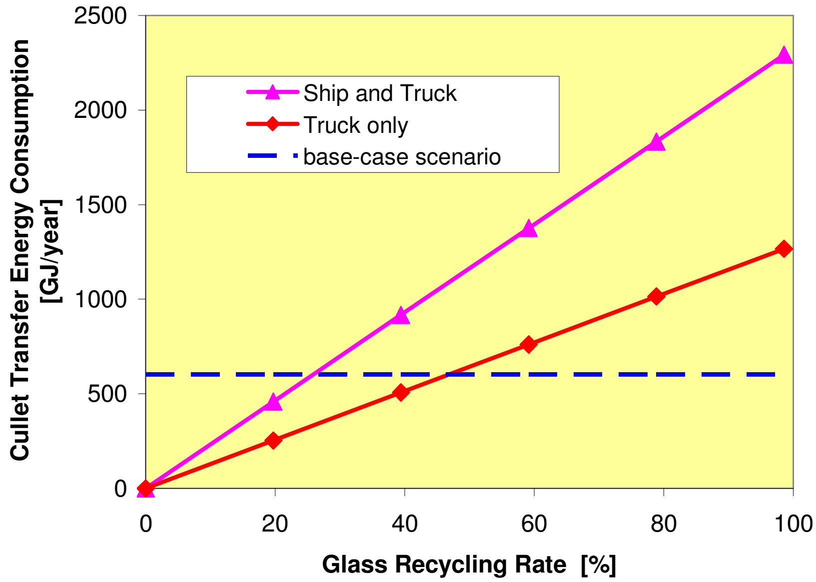


Figure 3.12: Effect of Cullet Transfer Mode on Transport Energy

In addition, the difference in cullet transfer energy consumption is likely to be less marked if the distances travelled are similar. In the scenario described above the ship must travel a significantly greater distance than the truck because it must navigate around the coast of England, as it clearly cannot follow the direct route of the truck. For other scenarios this may, however, not be the case. For instance, export of the cullet to Southern Spain; here, the distances travelled by sea and by road are likely to be much more similar.

3.1.7 Options for use of Recycled Glass

There is presently a diversification in the use of recycled glass, with diversion away from the traditional use in glass manufacture into areas such as aggregates replacement, filtration systems, sand-blasting, etc.

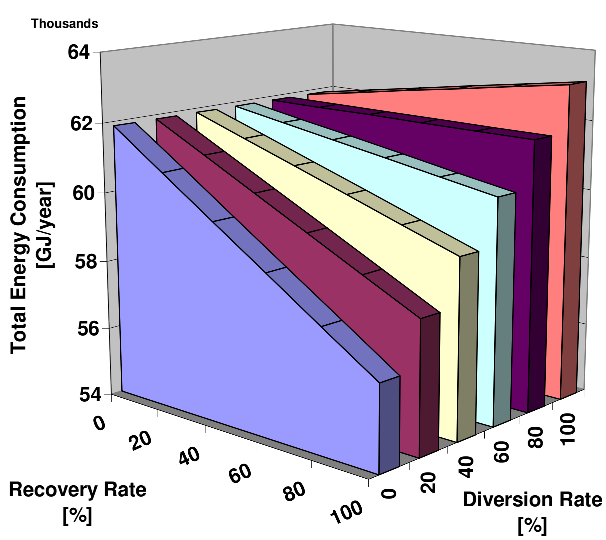


Figure 3.13: Effect of Diversion of Cullet to Aggregates Replacement

An example of the effect of this diversion is shown in Figure 3.13. For this scenario, recycling is via bottle banks only, and the amount of recycled glass, as cullet, being diverted for use as aggregates is then varied. The model assumes that the diverted cullet is transported 25 miles to its point of use (in, for example, local road construction) and that no further processing before use is required.

The graph shows that when no or low levels of recycled glass are diverted, the total energy consumed decreases with an increase in the recovery rate of glass. As the level of diversion increases the savings become less, and at high levels of diversion the energy consumption actually increases as the level of recycling is increased. This is because the energy savings made through use of recycled glass in the manufacturing process are progressively diminished as more glass is diverted for use as aggregates.

Indeed, when all the cullet is diverted, there is a 4.5% increase in energy consumption, compared to the base-case scenario (Figure 3.14). When comparing the energy consumptions at the maximum recycling rate, the value for 100 % diversion for aggregates use is 12.3 % greater than the consumption for the case where all the recycled glass is used in the manufacturing process. Hence, in terms of energy consumption it would not be desirable to divert collected glass away from use in glass manufacture.

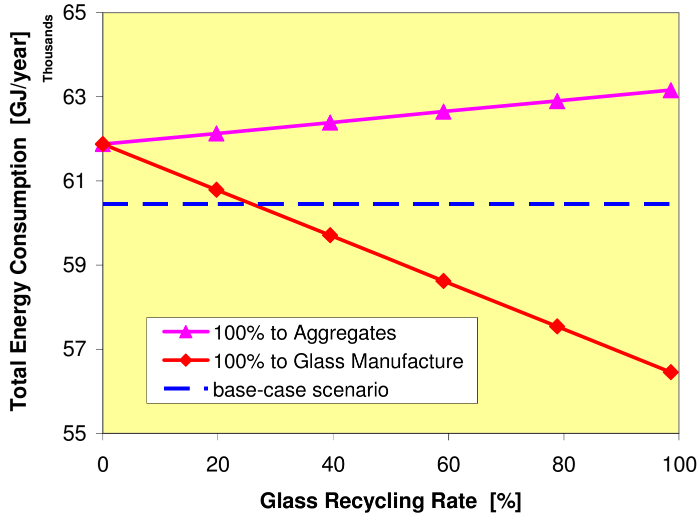


Figure 3.14: Comparison of Options for use of Recycled Glass

It should be noted that the determination of the consumption for both scenarios does not include that for the mining, etc., of raw materials used in glass manufacture or for traditional aggregates (see section 2.2). Thus, the results may vary somewhat if this is included in the glass waste chain/cycle, although it is expected that the use of recycled glass in manufacturing would still provide the best "energy" option.

3.2 PAPER & CARD FRACTION

As with the glass fraction, this section presents the results of various waste management scenarios. In particular, comparison is made of the different collection methods and the effect that incineration has on the energy consumption for the paper/card waste chain/cycle.

3.2.1 Energy Consumption of Waste Chain/Cycle Components

The annual energy consumption for the different stages of paper/card recycling and waste management, and how these vary with recycling rate is shown in Figures 3.15 and 3.16. The scenario represented here is for recycling via the PaperChain scheme (see section 2.3.3.1), combined with a fixed level of recycling via paper/card banks. This means that the amount of paper/card recycled via banks is fixed at the base-case scenario level (776.9 tonnes paper via bring-sites; 110.2 tonnes paper and 184.6 tonnes card via the HWRC), and the overall recycling rate is then increased by increasing the amount of paper collected from the PaperChain scheme. The vertical dashed line on the graphs represents the base-case scenario: the amount of paper/card via banks is as above, plus 3194 tonnes paper via the PaperChain scheme.

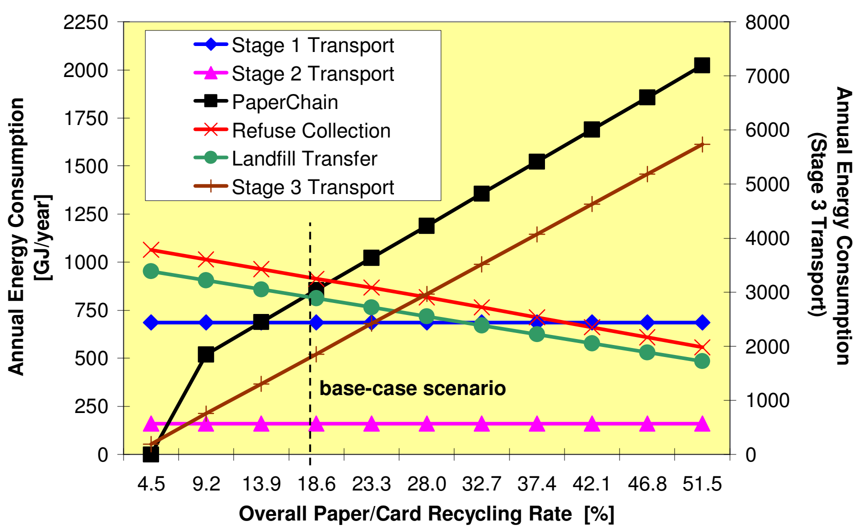


Figure 3.15: Effect of Paper/Card Recycling Rate on Energy Consumption (minor components)

Figure 3.15 shows that the energy consumption for stages 1 and 2 transport does not change with recycling rate, since the amount of paper/card collected via the banks is fixed. Both the energy consumed for the PaperChain scheme and stage 3 transport (transfer to the paper mill) do, however, increase as the recycling rate is increased. The increase is not completely linear for the PaperChain energy consumption since the recycling rate of 4.5 % represents zero recycling via the scheme (i.e. recycling via banks only; hence energy = 0).
The results also show that the maximum achievable recycling rate is only ~ 51.5 %. This is because the PaperChain scheme only collects newspapers and magazines (and leaflets – classified as newspapers/magazines for the purposes of the model), which represents only 49.7 % of the total amount of material available for the paper/card fraction; the remaining 1.8 % comes from the fixed amount of the paper/card collected via banks.

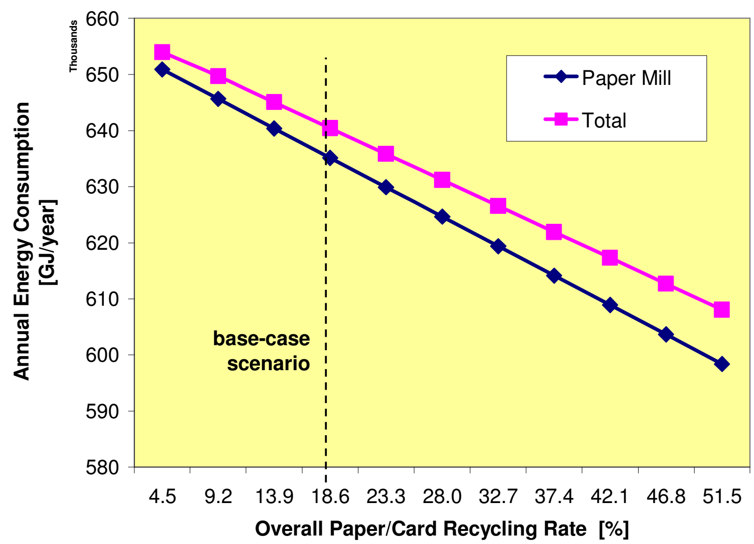


Figure 3.16: Effect of Paper/Card Recycling Rate on Energy Consumption (major components)

Despite this, Figure 3.16 shows that there is still quite a significant decrease in the total energy consumption as the recycling rate is increased. As with glass, the bulk of the energy consumed is in the manufacturing process, especially since a large amount of paper/card is manufactured (23,562 tonnes), requiring a great deal of energy. Thus, the relatively large savings in manufacturing energy offsets any increases in energy consumed in other areas of the paper/card waste chain/cycle.

The decrease in energy consumption represents an approximately 7.6 % decrease going from zero to maximum recycling. Compared to the base-case level of recycling (18.10 %), the decrease is ~ 5.1 % with maximum recycling (maximum recovery of newspapers/magazines).

3.2.2 Location of Paper Banks

For the base-case scenario, 776.9 tonnes paper is recycled from bring-sites (equivalent to ~ 35.3 tonnes per individual site) and 110.2 tonnes from the HWRC site. The card fraction is only recycled via the HWRC (184.6 tonnes), since no bring-site facilities for card currently exist in Southampton. Therefore, comparison can only be made for recycling of the paper at the two collection facilities.

In terms of the amount recycled, approximately 3.1 times more paper is recycled at the HWRC site than at individual bring-sites. With regard to the energy consumption, the opposite trend is, however, found: recycling via the HWRC requires approximately 5 times more energy (per tonne of paper collected) for the collection phase (stages 1 and 2 transport) than the bring-sites (Figure 3.17). As with the glass fraction, this is because of the greater distance travelled to the HWRC site (2.5 miles compared to ~0.26 miles for the bring-sites), and the proportion of journeys made specifically for recycling (100 % compared to 35.45 %).

Therefore, the results would suggest (as with glass) that, in terms of energy consumption, paper recycling facilities should not be located at the HWRC. Again, however, removing the facilities could lead to a drop in the recycling rate and, hence, possibly the energy consumption. Figure 3.18 compares the total energy consumption for scenarios with and without paper recycling facilities at the HWRC site. It is assumed that the amount recycled via the bring-sites remains the same for both scenarios.

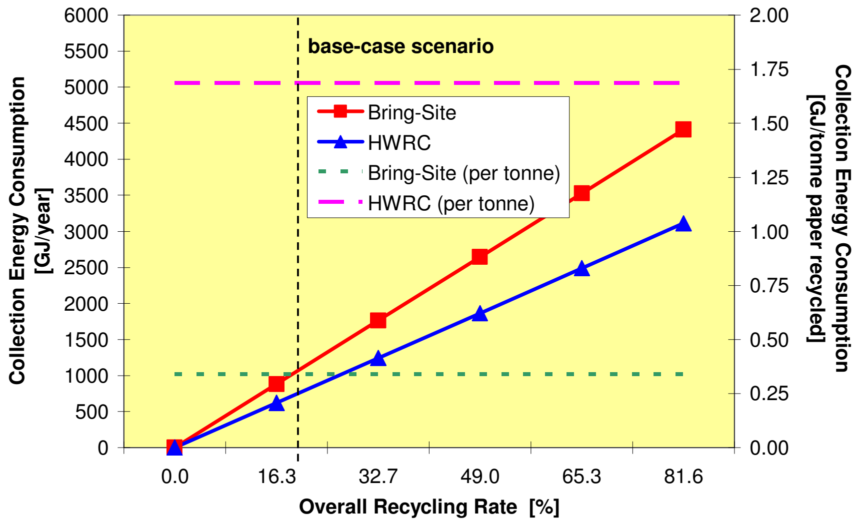


Figure 3.17: Comparison of Energy Consumption for Transport to Bring Sites and to a HWRC Site (Paper Fraction)

Firstly, it can be seen that the maximum recycling rate is reduced from 81.6 % with recycling at the HWRC site, to 73.8 % without recycling at the HWRC. Secondly, the total energy consumption at maximum recycling is greater when there is no recycling at the HWRC, with no additional paper recycled via the bring-sites. This is because the energy savings made through a decrease in the collection energy consumption is not sufficient to offset the increase in the paper manufacturing energy consumption due to a decrease in the amount of paper recycled.

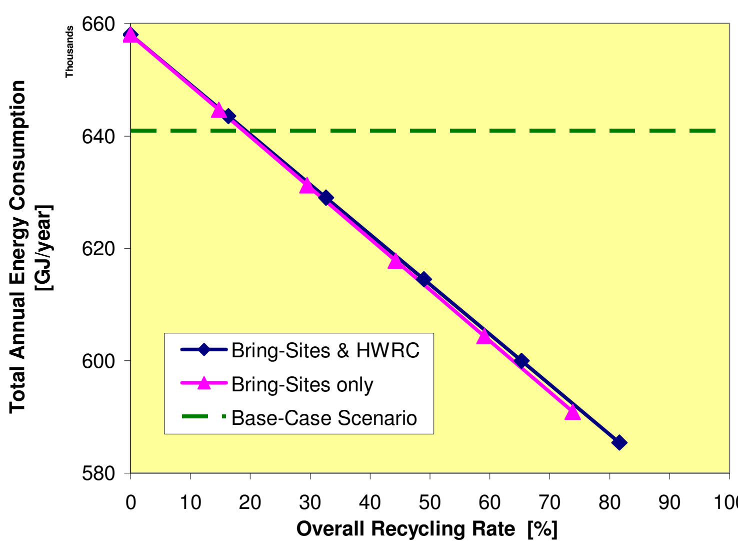


Figure 3.18: Effect of Removing Paper Bank from HWRC Site

Indeed, approximately 70 % of the paper "removed" (not recycled) from the HWRC site would need to be added to the bring-sites in order to give approximately the same total energy consumption for recycling via both the bring-sites and the HWRC (at the maximum recycling rate). This value of 70 % is, however, greater than the amount that might reasonably be expected to be added back if the paper recycling facilities were removed from the HWRC: based on the split between bring-sites and the HWRC for the base-case scenario the amount would only be ~ 32 %. Hence, although recycling via the HWRC requires more energy per tonne paper recycled, removal of the paper recycling facilities here could lead to a decrease in the overall amount recycled. This in turn would lead to an increase in the total energy consumption.

3.2.3 Collection Method

Comparison of the total energy consumption for the three different collection methods examined for the paper/card fraction (banks, PaperChain, Dry Recyclables) is shown in Figure 3.19. For each scenario recycling is only via the specified collection method. For instance, for the PaperChain and Dry Recyclables kerbside collection methods the amount of material recycled via the paper/card banks has been set to zero.

The graph shows that collection of the paper/card fraction via the dry recyclables kerbside collection scheme consumes the most energy (for a given level of recycling), whilst collection via the PaperChain scheme consumes the least energy. In between these two lies recycling via the paper/card banks.

The reason the PaperChain scheme has the lowest energy is mainly because the "collection-miles" for the kerbside scheme is much lower than the "transfer-miles" required to transfer the paper/card from the households to the WTS via the paper/card banks.

Therefore, it would also be expected that recycling via the dry recyclables kerbside scheme would also give a lower total energy consumption than recycling via the paper/card banks. The paper/card collected from the dry recyclables scheme is, however, sent for sorting at a MDR-MRF. The sorting at the MDR-MRF requires energy and, in addition, there are also losses associated with the sorting process. Hence, less material is sent to the paper mill, compared to recycling via the PaperChain scheme or via banks, since it is (presently) assumed that no losses are incurred for recycling via these methods: the paper/card is simply transferred from one stage to the next until it reaches the paper mill.

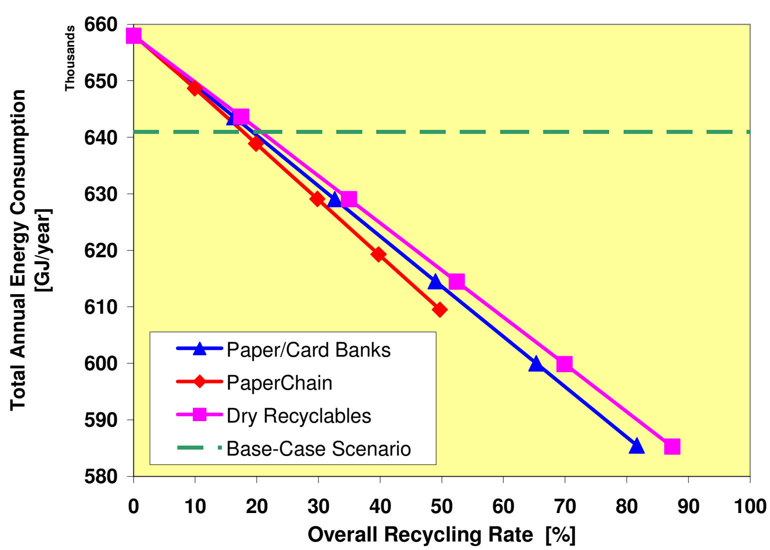


Figure 3.19: Effect of Recycling Method on Energy Consumption (Paper/Card Fraction)

This means that there will be less recycled paper/card used in the manufacturing process. Thus, the energy consumption for manufacture will be higher (for a given recycling rate) than for recycling via the other collection methods. Also, this energy consumption is high enough to offset the relatively low collection energy for the kerbside scheme. Hence, the total energy consumption is higher than for the other collection methods.
Although the PaperChain scheme has the lowest energy consumption (at a given recycling rate), the graph shows that the maximum overall recycling rate for the paper/card fraction with this scheme is only ~ 50 %. This compares to a rate of over 80 % for the other two collection methods. The differences in the maximum achievable recycling rates are due to the material that is recycled via the different methods, as detailed in section 2.3: only newspapers and magazines are recycled via the PaperChain scheme, whilst seven out of the nine sub-categories are recycled via the dry recyclables scheme. This can be seen graphically in Figure 3.20, which shows how the amount of material collected via each recycling method varies with recovery rate, and how this affects the overall recycling rate of the paper/card fraction.

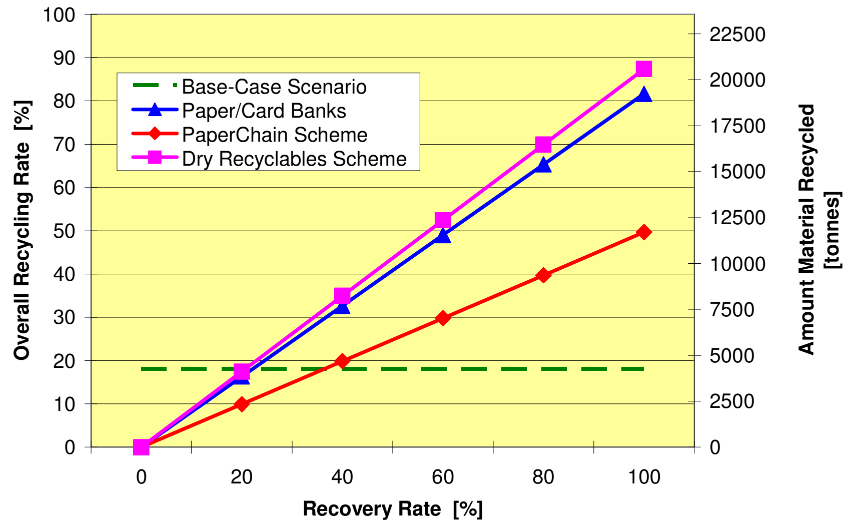


Figure 3.20: Material Recovery from different Recycling Methods (Paper/Card Fraction)

Therefore, comparison of the total energy consumption at the maximum achievable recycling rate (100 % recovery rate) for the different recycling methods shows that the PaperChain scheme has the highest energy consumption. This is because it collects the least amount of material for recycling, which is ultimately sent to the paper mill for use in the manufacturing process. Conversely, the dry recyclables scheme and recycling via the banks give similar levels of energy consumption. It would be expected that in practice, however, the actual levels of recycling that would be achievable from the dry recyclables scheme would be higher than the levels of recycling achievable from recycling via the paper/card banks, particularly without an increase in the number of paper/card banks located throughout the city. Hence, it is likely that the dry recyclables scheme would in practice give the lowest energy consumption.
Comparison of the energy savings at maximum recovery (of the appropriate materials) for the different schemes shows that there is a 4.9 % saving with recycling via the PaperChain scheme only (compared to the base-case scenario; 7.4 % compared to zero recycling). This increases to savings of 8.7 % both for recycling via banks only and via the dry recyclables scheme only (11.0 % and 11.1 %, respectively, compared to zero recycling).

Two scenarios have been examined here: the progressive replacement of recycling at paper/card banks with recycling via the dry recyclables kerbside collection scheme (Figure 3.21); and the progressive replacement of the PaperChain kerbside scheme with the dry recyclables scheme (Figure 3.22).

The first scenario (Figure 3.21) starts from the position where there is only recycling via the paper and card banks (kerbside coverage = 0 %). The recycling rate for this recycling method is kept fixed and assumed to be the same as the base-case scenario level, which has an overall recycling rate of 4.55 % (equivalent to a recovery rate of 5.57 %). More specifically, the recovery rate for the paper-based sub-categories is ~ 6 %, and for the card-based sub-categories it is ~ 4.2 %. The amount of material recycled with zero kerbside coverage is also assumed to be the same amount as for the base-case scenario for the banks (total = 1071.72 tonnes).

The proportion of the population covered by the kerbside dry recyclables scheme is then increased, and the total energy consumption determined for different recovery rates. As the proportion is increased the amount of material recycled via the banks is decreased according to equation (11).

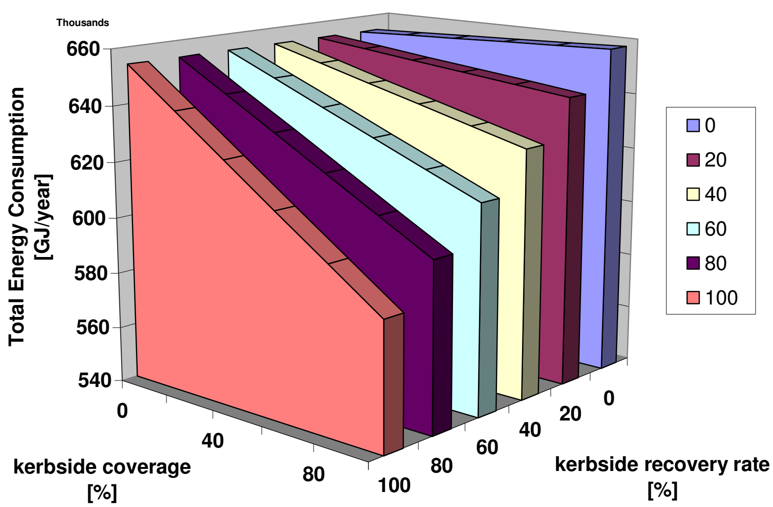


Figure 3.21: Replacement of Recycling via Banks with the PaperChain Scheme

The results show that the total energy consumption decreases as both the kerbside coverage and recovery rate are increased. This is because both serve to increase the amount of material collected for recycling. At zero kerbside recovery rate, however, there is an increase in the energy consumption with an increase in kerbside coverage, since less material is recycled. Indeed, for 100 % kerbside coverage no material is recycled, since there is no recycling via banks and the kerbside recovery rate is zero.

The second scenario (Figure 3.22) looks at the progressive replacement of the PaperChain scheme with the dry recyclables scheme, which is effectively what is happening within Southampton at present. For this scenario, however, it is assumed (for simplicity) that there is no material recycled via the paper and card banks.

The results here show, as expected, that the total energy consumption decreases with an increase in the kerbside recovery rate, since the amount of material collected for recycling increases. It is only at relatively high recovery rates, however, that the energy consumption decreases significantly as the proportion of the population covered by the dry recyclables scheme is increased. This is because, as mentioned earlier, although the dry recyclables scheme collects more material than the PaperChain scheme (for a given recovery rate), there is an energy consumption associated with the sorting of the dry recyclables at an MDR-MRF. In addition, there are losses associated with the sorting at the MDR-MRF. Hence, less material is sent to the paper mill than is collected for recycling. Thus, more energy is required for paper manufacture than for the same amount of material collected via the PaperChain scheme.

Therefore, it is not until high recovery rates that sufficiently more material is collected via the dry recyclables scheme (as the percentage coverage increases) than is collected via the PaperChain scheme at 100 % PaperChain coverage. At this point the energy consumption will be less, since more recycled material is now being used in paper manufacturing.

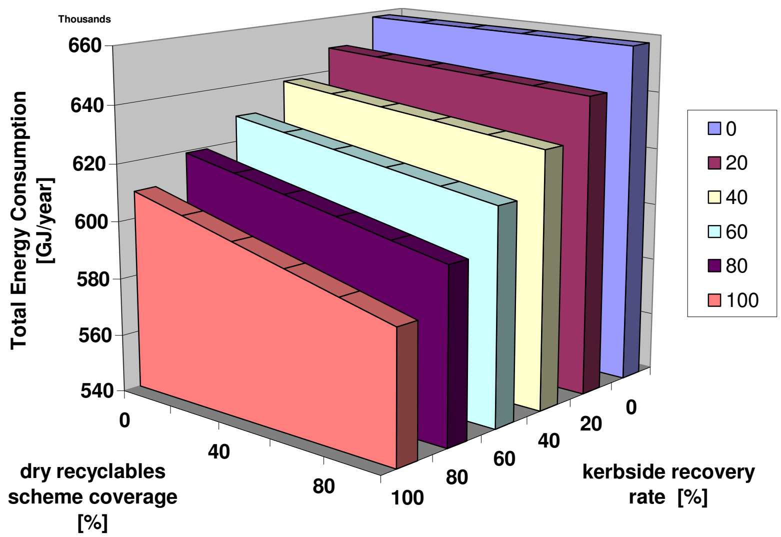


Figure 3.22 PaperChain versus Dry Recyclables Scheme

3.2.4 Incineration

The effect that incineration has on the energy consumption is examined by looking at various scenarios as follows:

1) recycling of the paper/card via bring-site/HWRC banks only, with variable recovery rate and landfill of the residual waste stream
2) no recycling of the paper/card, and variation of the level of incineration of the residual waste stream (with landfill of the remainder)
3) recycling via the paper/card banks with a 100 % recovery rate and variable levels of incineration
4) recycling via the dry recyclables scheme with a 100 % recovery rate and variable levels of incineration

The total energy consumption associated with each of these scenarios is shown in Figure 3.23. Firstly, it can be seen that, compared to scenario 1 (recycling-plus-landfill), scenario 2 (incineration-only) gives a much higher maximum reduction in energy consumption: 44.6 % over the base-case scenario (dashed line) compared to only 8.75 %. Because of the large

energy consumption associated with paper manufacture (cf. glass waste fraction) there is not, however, a point where there is a net energy gain.
Secondly, at levels of incineration of up to ~ 80 % (for scenario 3) or ~ 95 % (scenario 4), the scenario of recycling (100 %) plus incineration gives a lower energy consumption than the incineration-only scenario. At levels of incineration higher than this the opposite is, however, true.
This is generally because although recycling reduces the energy consumption associated with the paper and card waste chain/cycle, it also affects the amount and calorific value of the residual waste stream. The magnitude of these affects is, however, dependent on the scenario examined, as indicated below.
For scenario 3, where there is recycling via the paper/card banks, the amount of material recycled is relatively high (see Figure 3.20). Hence, the reduction in energy consumption due to recycling is fairly large. In addition, there will be a relatively high amount of energy produced from incineration, since a limited amount of material is removed from the refuse, compared to scenario 4. This is slightly offset, however, by the small decrease in the calorific value of the residual waste stream (see Figure 3.24). Thus, the overall affect is to give a lower energy consumption than the incineration-only scenario, unless very high levels of incineration are used.

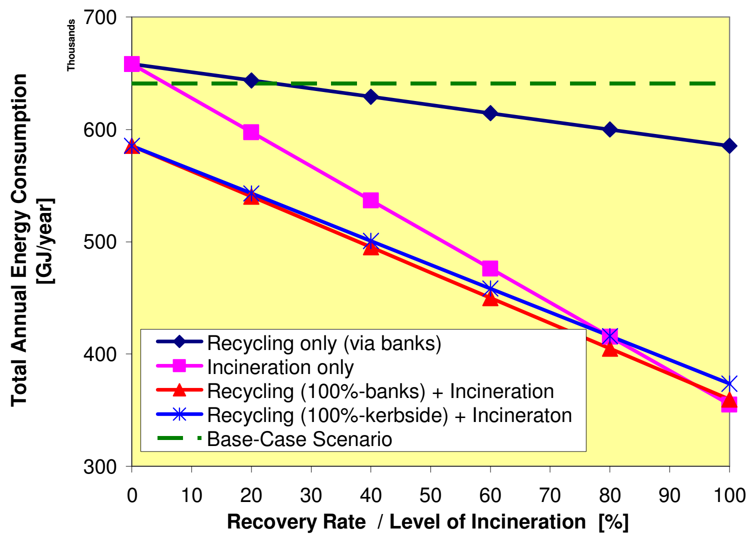


Figure 3.23: Comparison of Recycling and Incineration (Paper/Card Fraction)

For scenario 4, where material is collected via the dry recyclables scheme, the amount of paper/card material recycled is slightly higher than for scenario 3, as shown in Figure 3.20. Because of losses during the sorting process the manufacturing energy is, however, somewhat higher than for scenario 3. Hence, the energy consumption associated with the paper/card waste chain/cycle for scenario 4 is higher, as shown in Figure 3.19. In addition the energy produced from incineration is lower because the amount of residual waste is lower, since more material is recycled (not only paper/card, but also plastic bottles/containers and metal cans, which are also collected by the dry recyclables scheme). This is slightly offset, however, by the fact that the calorific value of the refuse increases slightly with recycling via the dry recyclables scheme (Figure 3.24). Thus, despite this, the overall effect is to cause the decrease in energy consumption (due to recycling) to be diminished as the level of

incineration is increased until, above a level of ~ 80 %, the energy consumption becomes greater than for the scenario with incineration only.
Hence, a combination of recycling plus incineration of the residual waste would generally be the best waste management option, unless high levels of incineration were incorporated as part of the waste management strategy.
As mentioned, recycling has an effect on the Calorific Value (CV) of the residual waste, and this is shown in Figure 3.24. The graph shows that the CV varies according to the type of recycling method. For recycling via the paper/card banks and also for the PaperChain the CV decreases with an increase in recycling because the paper/card has a CV that is slightly higher than the bulk CV of the refuse as a whole, so removing them from the residual waste stream will reduce its CV. The reduction is, however, small and not significant (~ 1.3 % for paper/card banks, ~ 1.5 % for the PaperChain scheme, compared to the value at 0 % recycling rate) because the difference between the CVs is not great.

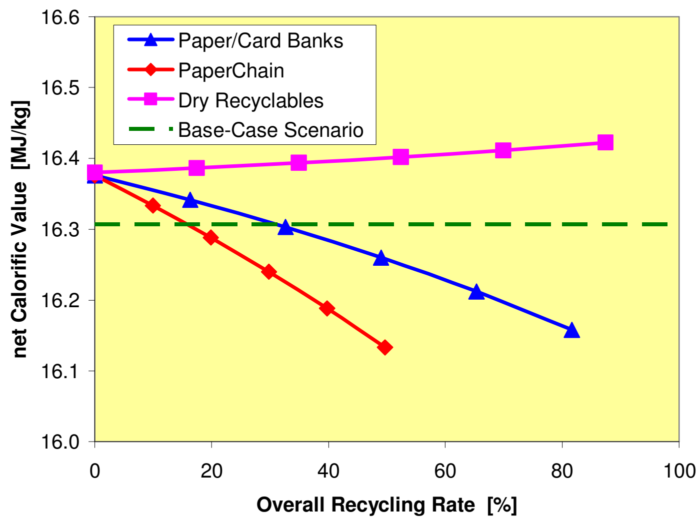


Figure 3.24: Effect of Recycling on Calorific Value of Residual Waste (Paper/Card Fraction)

Conversely, there is a slight increase in the CV with recycling via the dry recyclables scheme, although this is even less significant (~ 0.3 %). The CV increases because the kerbside scheme removes three types of material: plastics (high CV); paper/card (CV close to that of the refuse); and metals (effectively zero CV, although the labels do have some calorific value). Hence, there is a balance of positive, negative and neutral effects with this combination of materials, which has little effect on the overall CV of the refuse.

3.3 PLASTICS FRACTION

Recycling of the plastics fraction is presently very limited in Southampton and, indeed, generally throughout the United Kingdom. For the base-case scenario, only 43.95 tonnes are being collected per year from five bring-sites, and 9.224 tonnes from the HWRC site. This represents only ~ 0.5 % (53.174 tonnes) of the total amount of household plastics waste (11638 tonnes). The amount recycled is low firstly because, as mentioned in section 2.4, only plastic bottles and containers are presently recycled and these sub-categories represent only ~10.5 % of the total amount of plastics waste fraction (Figure 3.25). Furthermore, the amount of plastic bottles/containers collected via the plastic banks represents a recovery rate of only ~ 4.4 % for these materials.

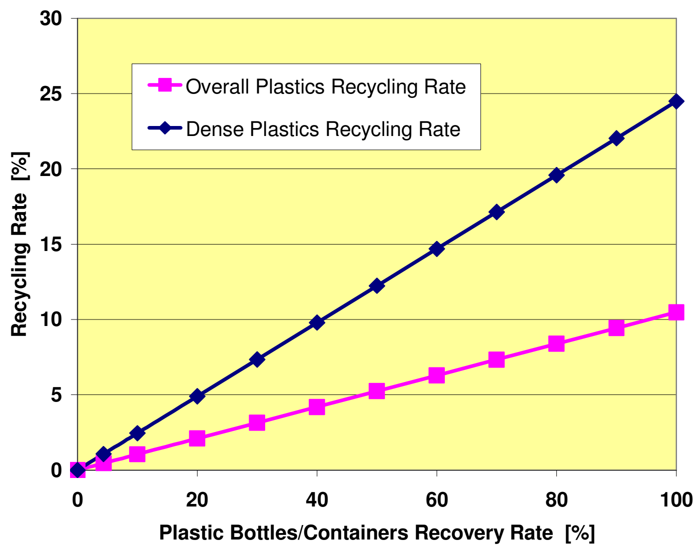


Figure 3.25: Effect of Plastics Bottles/Containers Recovery on Recycling Rate

In this section the results are expressed in terms of either the plastic bottles/containers recovery rate or the overall plastics recycling rate, where appropriate. The relationship between the two can be seen in Figure 3.25, which also shows how the recycling rate for the dense plastics category varies with the plastic bottles/containers recovery rate.

As mentioned, the model only presently accounts for recycling of plastic bottles/containers. Recycling of other plastics sub-categories does, however, take place, or is possible. This includes plastic (carrier) bags (plastic film category) and food and non-food packaging (dense plastics category). If these materials are included, then they could have a significant impact on the overall plastics recycling rate (Figure 3.26). The graph shows that maximum recovery of plastic carrier bags would account for recycling of 20.7 % of the plastics fraction, and 36.2 % of the 'Plastic Film' category. This assumes that two-thirds of the sub-category 'Refuse Sacks & Carrier Bags' are carrier bags, and that the refuse sacks are not recyclable.
Similarly, maximum recovery of the dense plastic food and non-food packaging sub-categories corresponds to 16.5 % recycling of the plastics fraction, and accounts for 38.5 % of the dense plastic category. Thus, recycling of plastic bottles/containers together with the food and non-food packaging would account for 63 % of the dense-plastic category. In turn, this would give a maximum overall recycling rate of 27 % for the plastic fraction. If all the above materials were recycled with a maximum recovery rate then this would give an overall recycling rate of 47.6 % for the plastics fraction.

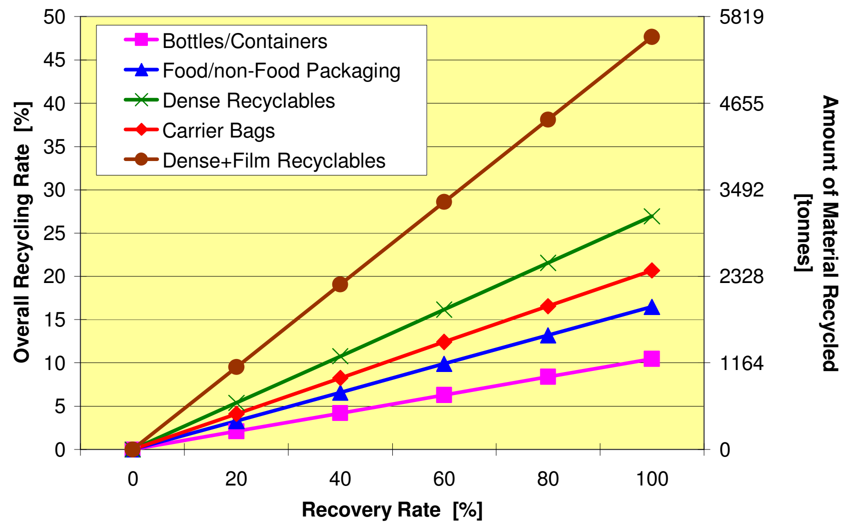


Figure 3.26: Effect of Material-specific Recovery on the Recovery Rate of the Plastics Fraction

3.3.1 Energy Consumption of Waste Chain/Cycle Components

Figures 3.27 and 3.28 show the effect that plastics recycling has on the energy consumption of the different stages of the waste chain/cycle associated with the recycling, processing and disposal of the plastics waste fraction. In this scenario, the plastics are recycled via banks only. It can be seen that there is a linear increase in the energy consumption associated with the recycling (collection, processing and transfer) stages. This is simply because, as more plastics are recycled, more trips and collections, etc., are required (for a fixed site density) to transfer this material from point A to point B, as has been detailed for the other waste fractions. Similarly, energy consumption associated with the disposal of the residual waste stream decreases (linearly), since less material requires disposal.

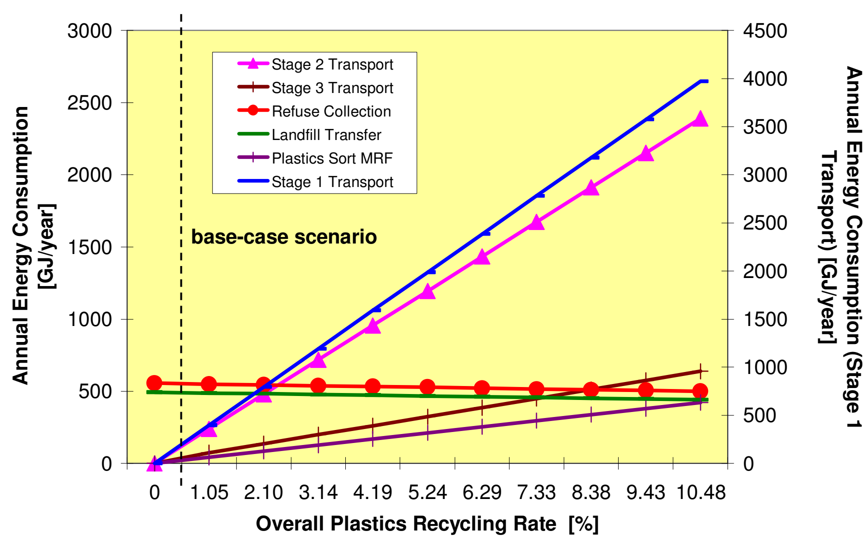


Figure 3.27: Effect of Plastics Recycling Rate on Energy Consumption (minor components)

It can be seen (Figure 3.28) that the manufacturing process for the plastics consumes the most energy, and it is also here that the greatest energy savings can be made through increased use of recycled material in the manufacturing process. Indeed, savings of more than 65% can be achieved using the maximum possible amount of plastic bottles/containers that can be recycled in Southampton. As before, any increases in the energy consumption due to increased recycling are offset by the relatively large energy savings from use of plastics made from recycled material.

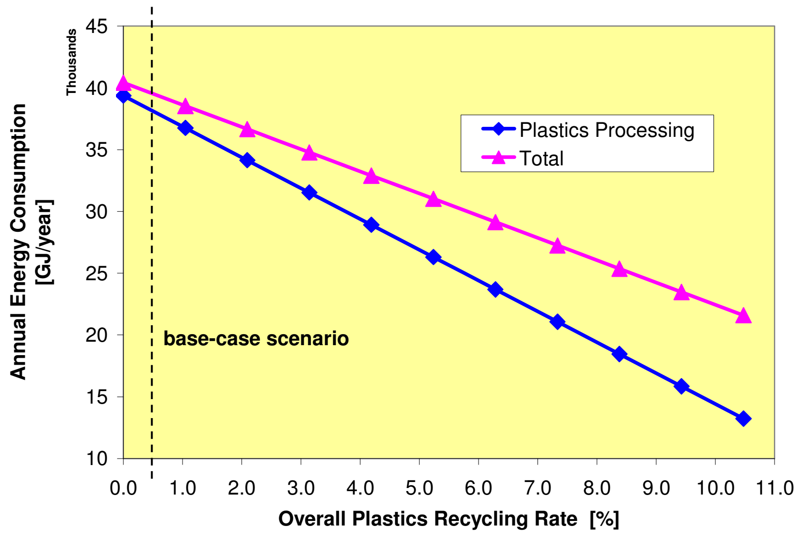


Figure 3.28: Effect of Plastics Recycling Rate on Energy Consumption (major components)

The results show that the maximum savings in energy are 45.5 % (at a 10.5 % overall recycling rate) compared to the base-case scenario (recycling rate of 0.5 %), or 46.6 % compared to no recycling at all. These large savings are, however, only related to those plastics that are presently recycled, which represents, as mentioned, only ~ 10.5 % of the total amount of plastics used in Southampton. Hence, the savings would be considerably less if the energy consumption required to produce all of the plastics used (11639 tonnes) was included in order to determine the total energy consumption for the plastics waste cycle.

3.3.2 Location of Plastic Banks

For the base-case scenario 43.95 tonnes plastic bottles/containers are recycled from bring-sites (equivalent to 8.79 tonnes per individual site) and 9.22 tonnes from the HWRC site. This equates to approximately five-percent more plastics being recycled at the HWRC site than at individual bring-sites.

In terms of the collection (stages 1 and 2 transport) energy consumption (Figure 3.29) transfer via the bring-sites consumes overall much more energy than via the HWRC, although per individual bring-site it is only approximately 5.5 % more energy. If, however, the consumption is expressed in terms of energy per tonne of plastics collected then the difference is greater: ~ 5.6 GJ/tonne collected for the recycling at the bring-sites, compared to only ~ 3.4 GJ/tonne for the HWRC site. This is 63 % more energy consumption per tonne for the bring-sites, which is the opposite trend than was found for the glass and paper/card fractions.

Although the average distance travelled to the bring-sites (~ 0.55 miles) is still less than the distance travelled to the HWRC site (2.5 miles), it is greater than for the other two waste fractions, because of the low number of plastic banks (5) for the base-case scenario. Additionally, the percentage of journeys made specifically for recycling (37.65 %) is also higher than before. Despite this, it would still be expected that the energy consumption per tonne collected would be higher for the HWRC site. If the transfer-miles are, however, determined for each of the locations, it is found that a greater total distance is travelled to bring-sites (~ 555 miles/tonne material recycled) than to the HWRC (250 miles/tonne) It should be noted that the value for the HWRC accounts for the fact that the plastics fraction represents only a part of the total load taken to the HWRC per trip.

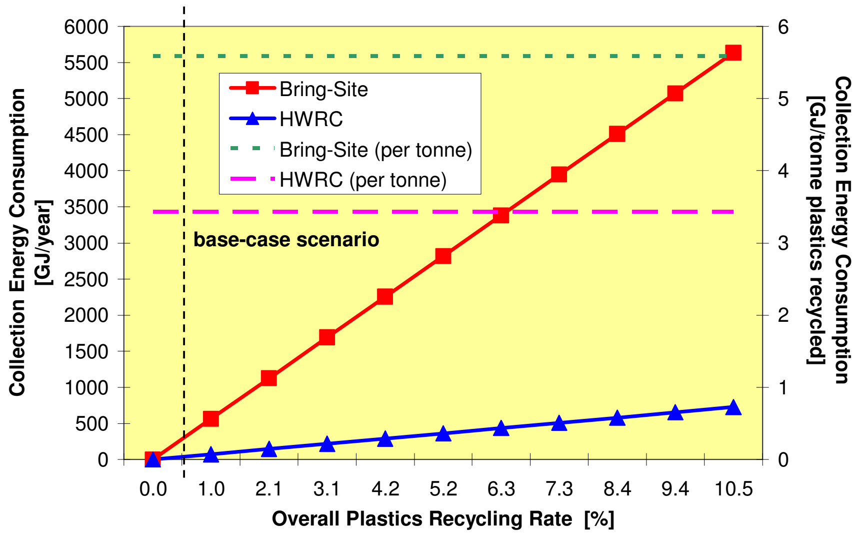


Figure 3.29: Comparison of Energy Consumption for Transport to Bring Sites and to a HWRC Site (Plastics Fraction)

The reason that the distance travelled in order to transfer one tonne of plastics is higher for the bring-sites is mainly due to a change in the amount of material transferred per trip. For the glass and paper/card the amount is 4.5 kg, but for plastics this is reduced to 0.75 kg because of its greater volume-to-weight ratio. Thus, decreasing the amount transferred per trip results in the need for considerably more trips in order to transfer the plastics to the bring-sites. Hence, the shorter journey distance is offset by the extra number of trips that are required.

The results would suggest that, in terms of energy consumption, plastics recycling facilities should not be located at bring-sites. Removal of the facilities could, however, lead to a drop in the recycling rate and, hence, possibly the energy consumption. Indeed, it could be argued that it would be better to increase the number of plastics banks located throughout the city. This would, hopefully, increase the amount of material recycled through bring-sites, whilst at the same time decreasing the distance travelled to the sites and percentage of trips made specifically for recycling, which should lead to a decrease in the energy consumption per tonne recycled.

It should be noted that if the amount were increased to 4.5 kg, then the plastics fraction would exhibit the same trend as was found with the other material. Hence, the results show the sensitivity of the model to various parameters, and the need for accurate information regarding the amounts of material taken to bring-sites and the HWRC. Indeed, as mentioned in section 2.2.1.1**,** the model presently assumes separate transfer of material to the bring-sites, and does not account for the possibility of transferring more than one type of material per trip. This would, however, require a certain amount of development to the model, but will be addressed in phase two of the Energy Footprint Project under the SUE Waste Consortium programme.

3.3.3 Collection Method

Comparison of the total energy consumption for the two different collection methods examined for the plastics fraction is shown in Figure 3.30. For each scenario recycling is only via the specified collection method. For instance, for the Dry Recyclables kerbside collection method the amount of material recycled via the plastics banks has been set to zero.

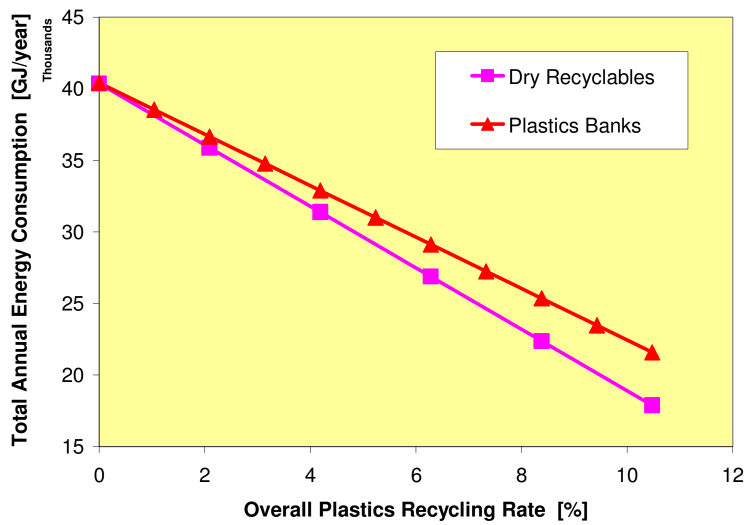


Figure 3.30: Effect of Recycling Method on Energy Consumption (Plastics Fraction)

The graphs show that collection of the plastics fraction via the dry recyclables kerbside collection scheme consumes less energy than recycling via the plastics banks (17 % less at maximum recovery). This is the opposite trend as was found for the paper/card fraction. The main reason for this is because the collection-miles for the kerbside scheme (~ 2 miles per tonne at maximum levels of recycling, although this distance is variable due to variable total transfer distance – see section 3.3.4 for further discussion about this) are much lower than the transfer-miles required to transfer the plastics from the households to the WTS via the plastics banks (~ 570 total miles per tonne; i.e. sum of miles via bring-sites and via HWRC – see section 3.6.2 for more details). As indicated in section 3.3.2, there is a reduced mass of plastics transferred per trip for plastics when compared to paper/card. Hence, the transfer-miles per tonne will be more for the plastics than they are for the paper/card fraction.

As before, there are, however, sorting losses associated with the plastics collected via the kerbside scheme. In fact, losses are encountered twice: at the MDR-MRF, which separates the plastics from the other material; and at the plastics sort MRF, which separates out the different types of plastics. But the plastics collected via the banks are also sent to the plastics sort MRF so losses (although less) are also associated with this collection method.

Thus, there will be less recycled plastics sent to the processing plant for collection via the kerbside scheme, resulting in a higher energy consumption associated with processing of the plastics. The difference in processing energy consumption is, however, not enough to offset the higher transfer energy consumption associated with collection via the plastics banks. The energy savings with maximum recycling are 54.9 % compared to the base-case scenario (55.8 % compared to zero recycling).

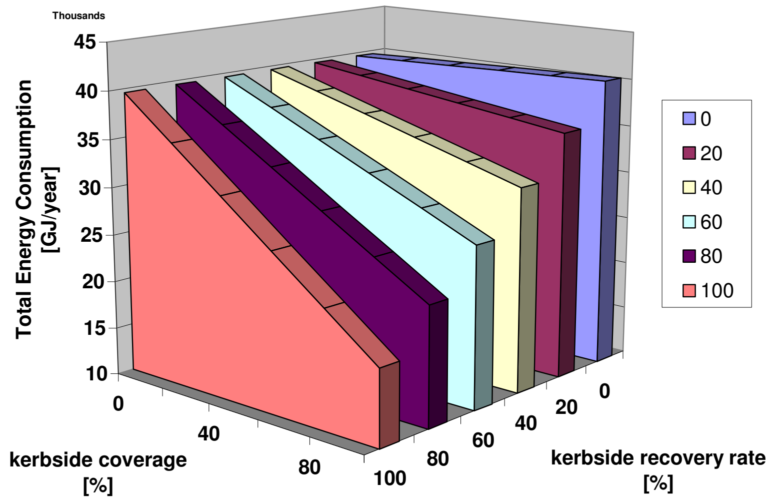


Figure 3.31: Replacement of Recycling via Plastics Banks with Kerbside Dry Recyclables Scheme

Figure 3.31 examines the effect of the progressive replacement of recycling at banks with recycling via the dry recyclables kerbside collection scheme. The scenario starts from the position where there is only recycling via the banks (kerbside coverage = 0 %). The recycling rate for this recycling method is fixed and assumed to be the same as the base-case scenario level, which has an overall recycling rate of 0.46 % (equivalent to a recovery rate of 4.36 %**).** The amount of material recycled with zero kerbside coverage is also assumed to be the same amount as for the base-case scenario for the banks (total = 53.174 tonnes).

The proportion of the population covered by the kerbside dry recyclables scheme is then increased, and the total energy consumption determined for different recovery rates. As the proportion is increased, the amount of material recycled via the banks is decreased according to equation (11).

The results show that the total energy consumption decreases as both the kerbside coverage and recovery rate are increased. This is because both serve to increase the amount of material collected for recycling. At zero kerbside recovery rate there is, however, an increase in the energy consumption since less material is recycled. Indeed, for 100 % kerbside coverage no material is recycled.

3.3.4 Refuse Collection Frequency

The model presently assumes that the dry recyclables kerbside scheme makes fortnightly collections, and that this is complimented by alternate fortnightly collection of the residual household waste (refuse). This is the present scenario for those areas of Southampton that are operating the dry recyclables scheme that was introduced in October 2003, and was being phased-in throughout the city. The expansion of the scheme has, however, been suspended until concerns over health issues (pests and smells) relating to a fortnightly refuse collection have been addressed. This could mean that the fortnightly collection of the residual waste stream would be replaced by a weekly collection, whilst maintaining a fortnightly collection of the dry recyclables[5].

[5] At an Extraordinary Meeting on 6th October 2004, Council officials voted to re-instate weekly collections of the refuse whilst maintaining a fortnightly collection of the dry recyclables.

Hence, both the above scenarios have been examined in order to assess the effect that the collection frequency for the refuse has on the energy consumption associated with this (Figure 3.32). The graph shows that, on average, the refuse collection energy consumption is ~ 12.6 % higher for a weekly collection than for a fortnightly collection.

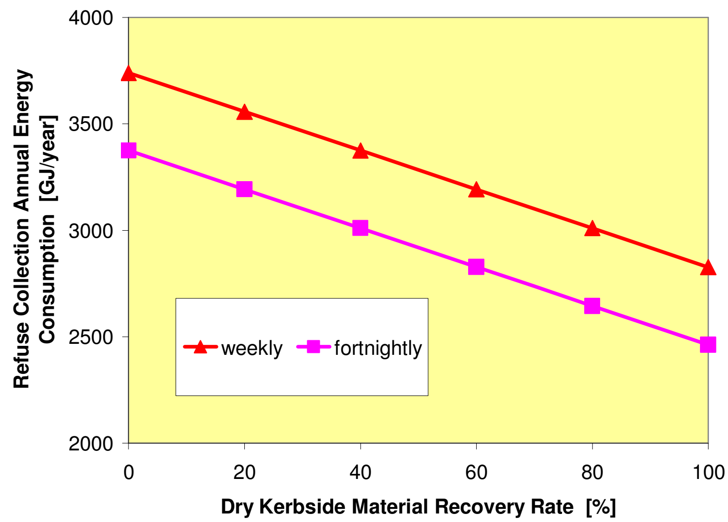


Figure 3.32: Effect of Refuse Collection Frequency on Energy Consumption

This is because, although the same amount of refuse is collected annually (for a given dry recyclables recovery rate), the distance travelled is greater with a weekly collection frequency, as discussed in section 2.2.7.

3.3.5 Incineration

As with other waste fractions, the model for the plastics fraction also includes the option to incinerate, rather than landfill, the residual waste stream. The effect that incineration has on the total energy consumption has been examined by comparing the base-case scenario with the following other scenarios:

1) recycling of the plastics via bring-site/HWRC plastics banks with variable recovery rate, and landfill of the residual waste stream
2) no recycling of the plastics, and variation of the level of incineration of the residual waste stream (with landfill of the remainder)
3) recycling via the plastics banks with a 100 % recovery rate and variable levels of incineration
4) recycling via the dry recyclables scheme (100 % recovery rate) and variable levels of incineration

Firstly, the results (Figure 3.33) show that, compared to recycling with landfill of the residual waste stream, incineration without recycling gives a much greater maximum reduction in energy consumption. Secondly, the combination of recycling via plastics banks and incineration (scenario 3) gives a lower energy consumption than just incineration (scenario 2). This is because of the savings in energy consumption associated with recycling, which adds to the reduction in the total energy consumption.
With recycling via the dry recyclables scheme plus incineration (scenario 4) there is, however, a cross-over point (~30 % incineration level) where the energy consumption is higher than with incineration alone. This is because recycling via the kerbside scheme

significantly reduces the amount of residual waste available for incineration, since the scheme removes paper/card and metal cans as well as plastic bottles/containers from the waste stream. Thus, the amount of energy produced from incineration in this case will be lower than with incineration alone. This is because the fixed decrease, due to recycling, in the energy ***consumption*** for the production of the plastics (when compared to scenario 2) is offset by the decrease in the energy ***production*** from incineration. This offset becomes more dominant as the level of incineration is increased, thus causing the cross-over from less to more energy consumption, when compared to scenario 2.

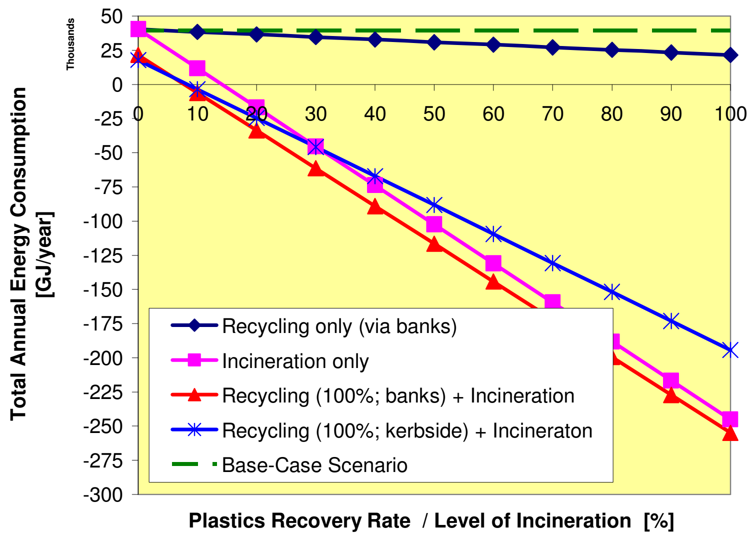


Figure 3.33: Comparison of Recycling and Incineration (Plastics Fraction)

As well as affecting the amount of residual waste available for incineration, recycling also has an effect on the CV of the residual waste (Figure 3.34). The graph shows that the CV varies according to the type of recycling method. For recycling via plastics banks the CV decreases with an increase in recycling because the plastics have a relatively high CV (when compared to the bulk CV of the refuse as a whole), so removing them from the residual waste stream will reduce its CV. The reduction is, however, small and not significant (~ 1.6 % compared to the value at 0 % recycling rate) because the amount of plastics removed from the refuse is small.

Conversely, there is an increase in the CV with recycling via the dry recyclables scheme, although the change is even less significant (~ 0.3 %). This is because the kerbside scheme removes three types of material, each if which serves to counteract the effect on the CV of the other, as has been discussed in section 3.2.4.

Also, it can be seen that the CVs at zero recycling rate are not the same. For this scenario, with recycling via the plastics banks, all the plastics recycled for the base-case scenario are diverted back into the residual waste stream. For recycling via the dry kerbside scheme, however, not only are the plastics diverted back, but also the paper/card and metal cans that are recycled at the base-case scenario. Thus, the composition at zero recycling is not the same for the two different collection methods, and the effect is to give a higher CV for the dry recyclables scheme.

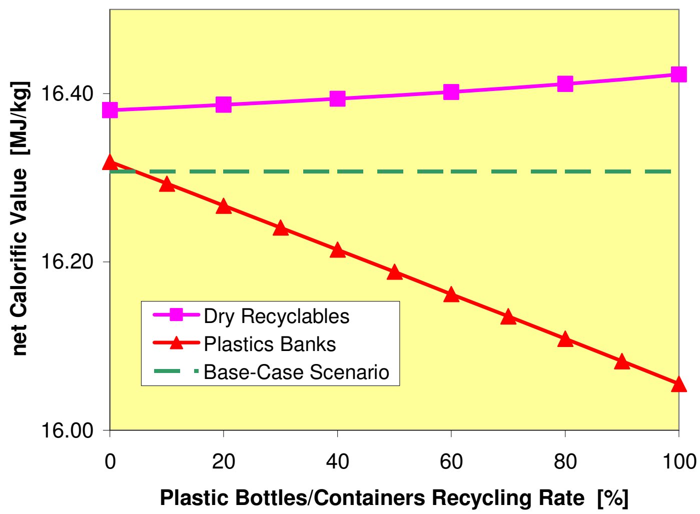


Figure 3.34: Effect of Recycling on Calorific Value of Residual Waste (Plastics Fraction)

3.4 METALS FRACTION

Although there are several different sub-categories of the metals waste fraction that are recyclable, only scenarios involving recycling of metal cans (food and beverage) are considered in this report. This is because they have the greatest potential for an increase in the level of recycling, since only 1.6 % of these sub-categories of the metals fraction are presently recovered. In addition, the infrastructure arrangements for the management of the other sub-categories are not fully known at the present time. This will be addressed in phase two of the Energy Footprint project. Recycling of the other metal sub-categories will be examined at that time. It would be expected, however, that similar trends of energy consumption versus recycling rate will also be found for these materials.

3.4.1 Energy Consumption of Waste Chain/Cycle Components

Figures 3.35 and 3.36 show the effect that recycling of metal cans has on the energy consumption of the different stages of the waste chain/cycle associated with the recycling, processing and disposal of the metals waste fraction. In this scenario, the metal cans are recycled via banks only. It can be seen that there is a linear increase in the energy consumption of the components associated with the recycling (collection, processing and transfer) of the metal cans. This is simply because, as more metal cans are recycled, more trips and collections, etc., are required (for a fixed site density) to transfer this material from point A to point B. Similarly, energy consumption associated with the disposal of the residual waste stream decreases (linearly), since less material requires disposal. The energy consumption for the scrap merchant stage is constant, since this is associated with the other sub-categories of metals, whose recycling rate is fixed.

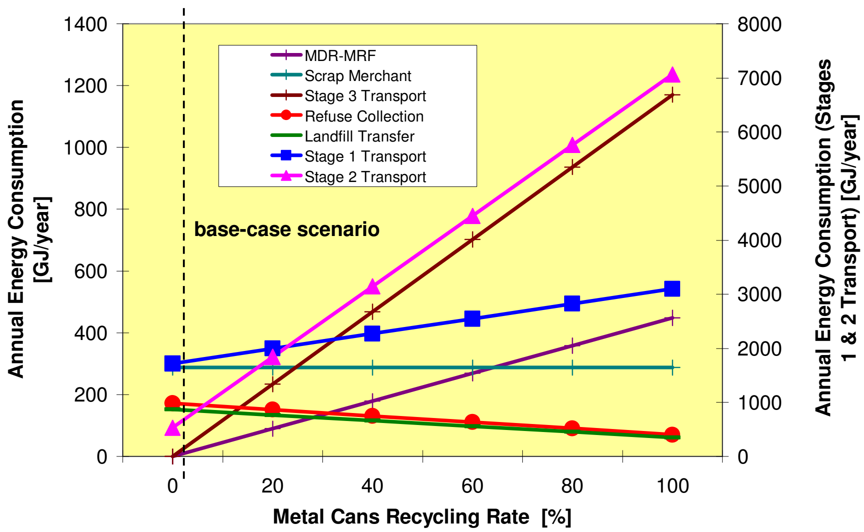


Figure 3.35: Effect of Metal Cans Recycling Rate on Energy Consumption (minor components)

It can be seen (Figure 3.36) that the processing/manufacture of the metals consumes the most energy. It is, however, also here that the greatest energy savings can be made through increased use of recycled material in the manufacturing process, with more than 30 % savings using the maximum possible amount of material that can be recycled in Southampton.

It should be noted that the energy consumption for the processing/manufacturing component is for all the metals within Southampton, except aerosols, batteries and white goods, since it

is hard to quantify the amount and type of metals within these materials. For the base-case scenario this includes the use of recycled metals (both ferrous and non-ferrous cans and other metals sub-categories). The savings are, however, those made through the use of recycled metal cans only, since the above scenario only looks at the variation in the amount of these materials that are recycled.
The results show that the maximum savings in energy is 26.2 % (at a 100 % metal cans recovery rate) compared to the base case scenario (recovery rate of 1.6 %), or 26.5 % compared to no recycling at all.

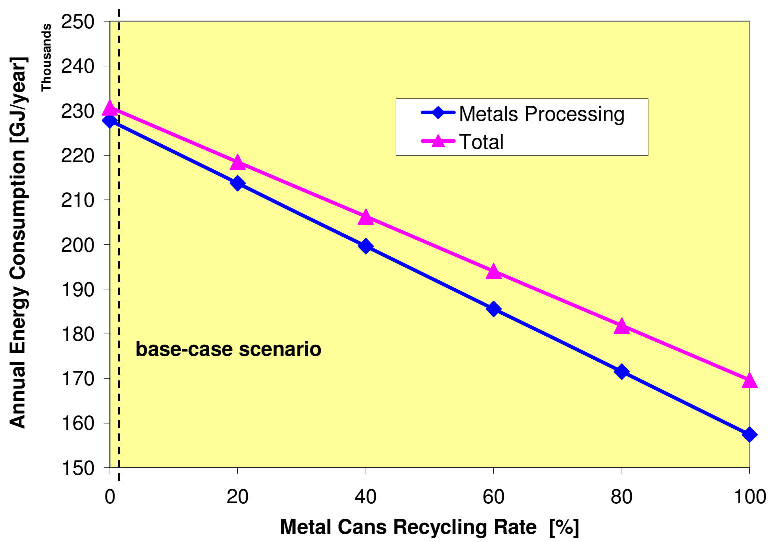


Figure 3.36: Effect of Metal Cans Recycling Rate on Energy Consumption (major components)

3.4.2 Location of Metal Cans Banks

For the base-case scenario, 32.79 tonnes mixed metal cans are recycled from bring-sites (equivalent to ~ 6.56 tonnes per individual site) and 1.53 tonnes from the HWRC site. In terms of the amount recycled, approximately 4.3 times more metal cans are recycled at individual bring-sites than at the HWRC site. This is the opposite trend than found for the other waste fractions. The reasons for this are not known, although are simply likely to be due to people's recycling habits.
In terms of energy consumption the opposite trend is, however, found: recycling via the HWRC requires approximately three times more energy (per tonne of metal cans collected) for the collection phase (stages 1 and 2 transport) than the bring-sites (Figure 3.37). As with the glass and paper/card fractions, this is because of the greater distance travelled to the HWRC site (2.5 miles compared to ~0.553 miles for the bring-sites), and the proportion of journeys made specifically for recycling (100 % compared to 37.65 %). This is discussed in more detail in section 3.6.2.
Therefore, the results would suggest that, in terms of energy consumption, metal cans recycling facilities should not be located at the HWRC. Again, however, removing the facilities could lead to a drop in the recycling rate and, hence, possibly the energy consumption.

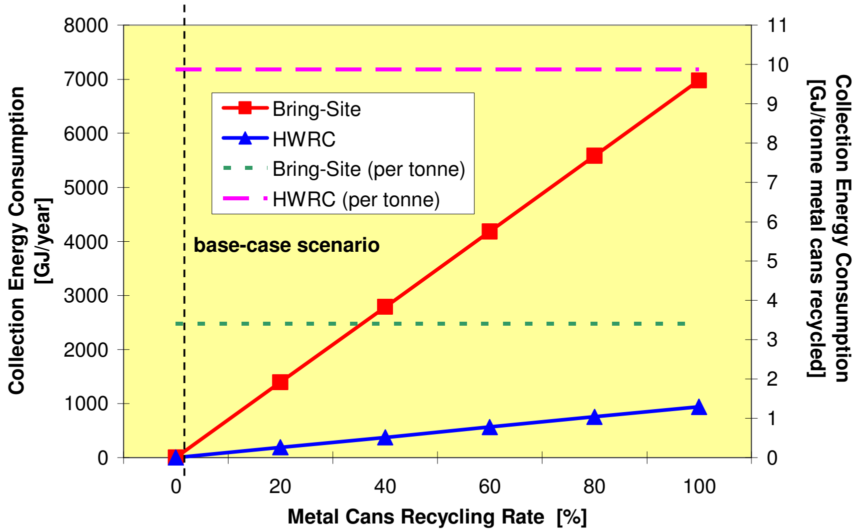


Figure 3.37: Comparison of Energy Consumption for Transport to Bring Sites and to a HWRC Site (Metals Fraction)

3.4.3 Collection Method

Comparison of the total energy consumption for the two different collection methods examined for the metals fraction (banks and dry recyclables scheme) is shown in Figure 3.38. For each scenario recycling is only via the specified collection method.

The graphs show that collection of the metal cans via the dry recyclables kerbside collection scheme consumes less energy than recycling via the mixed metals cans banks (4.5 % less at maximum recovery). This is the same trend as was found for the plastics fraction. The main reason for this is because the collection-miles for the kerbside scheme (~ 2 miles per tonne at maximum levels of recycling) are, once more, much lower than the transfer-miles required to transfer the metal cans from the households to the WTS via the cans banks (~ 210 miles per tonne).

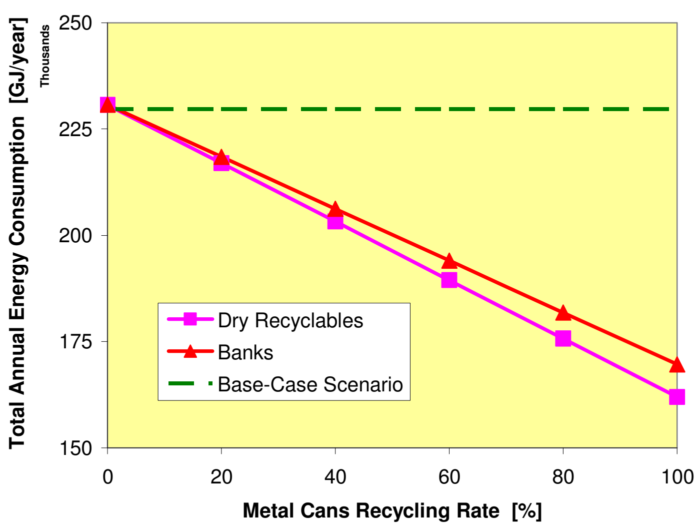


Figure 3.38: Effect of Recycling Method on Energy Consumption (Metals Fraction)

As before, there are sorting losses associated with the metal cans collected via the kerbside scheme. The metal cans collected via the banks are, however, also sent to the MDR-MRF for sorting, so encounter the same losses. Thus, there will be the same amount of recycled metal cans (per tonne input) sent to the processing plant from the MDR-MRF for both recycling methods. Therefore, it is only the effect of transfer distance that gives rise to the differences in total energy consumption for the different recycling methods. Hence, the differences are less than were found for the other waste fractions.

The energy savings with maximum recycling are 29.5 % compared to the base-case scenario (29.8 % compared to zero recycling).

Figure 3.39 shows the examination of the effect of the progressive replacement of recycling at banks with recycling via the dry recyclables kerbside collection scheme. The scenario is as described for the plastics fraction (section 3.3.3), although the fixed level of recovery via the metal cans banks is 1.6 %. The amount of material recycled with zero kerbside coverage is also assumed to be the same amount as for the base-case scenario for the banks (total = 34.32 tonnes).

The proportion of the population covered by the kerbside dry recyclables scheme is then increased, and the total energy consumption determined for different recovery rates. As the proportion is increased, the amount of material recycled via the banks is decreased according to equation (11).

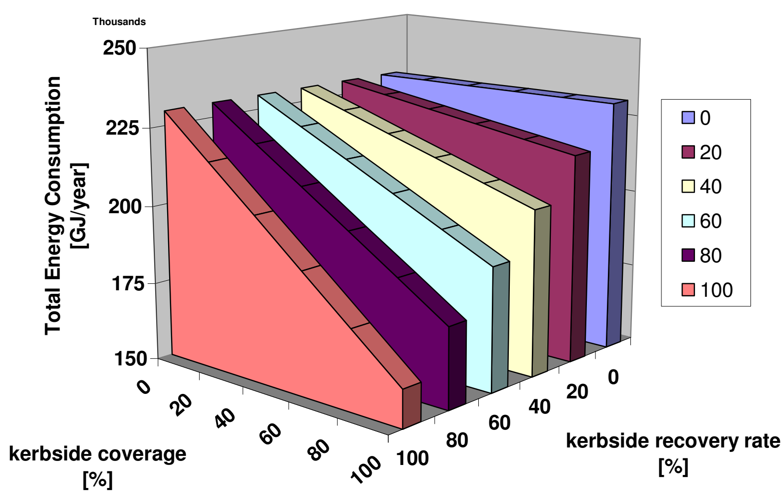


Figure 3.39: Replacement of Recycling via Metal Cans Banks with Kerbside Dry Recyclables Scheme

The results show that the total energy consumption decreases as both the kerbside coverage and recovery rate are increased, since both serve to increase the amount of material collected for recycling. At zero kerbside recovery rate there is, however, an increase in the energy consumption since less material is recycled. Indeed, for 100 % kerbside coverage no material is recycled.

3.4.4 Incineration

The model also includes the option to incinerate, rather than landfill, the residual waste stream. The effect that incineration has on the total energy consumption has been examined by comparing the base-case scenario with the following other scenarios:

1) recycling of the metal cans via bring-site/HWRC mixed metal cans banks with variable recovery rate, and landfill of the residual waste stream
2) no recycling of the metal cans, and variation of the level of incineration of the residual waste stream (with landfill of the remainder)
3) recycling via the metal cans banks with a 100 % recovery rate and variable levels of incineration
4) recycling via the dry recyclables scheme (100 % recovery rate) and variable levels of incineration

Firstly, the results (Figure 3.40) show that, compared to recycling with landfill of the residual waste stream, incineration without recycling gives a much higher maximum reduction in energy consumption. Secondly, the combination of recycling via metal cans banks and incineration (scenario 3) gives a lower energy consumption than just incineration (scenario 2). This is because of the savings in energy consumption associated with recycling, which adds to the reduction in the total energy consumption.
With recycling via the dry recyclables scheme plus incineration (scenario 4) the difference between this scenario and the incineration-only scenario becomes less as the level of incineration is increased. Indeed, at a level of ~ 95 % there is a cross-over point where the energy consumption is higher than with incineration alone, although only slightly. This is because recycling via the kerbside scheme significantly reduces the amount of residual waste available for incineration, since the scheme removes paper/card and plastic bottles/containers as well as metal cans from the waste stream. Thus, the amount of energy produced from incineration in this case will be lower than with incineration alone. This is because the fixed decrease, due to recycling, in the energy consumption for the processing/manufacture of the metals (when compared to scenario 2) is offset by the decrease in the energy production from incineration. This offset becomes more dominant as the level of incineration is increased, thus causing the cross-over from less to more energy consumption, when compared to scenario 2.

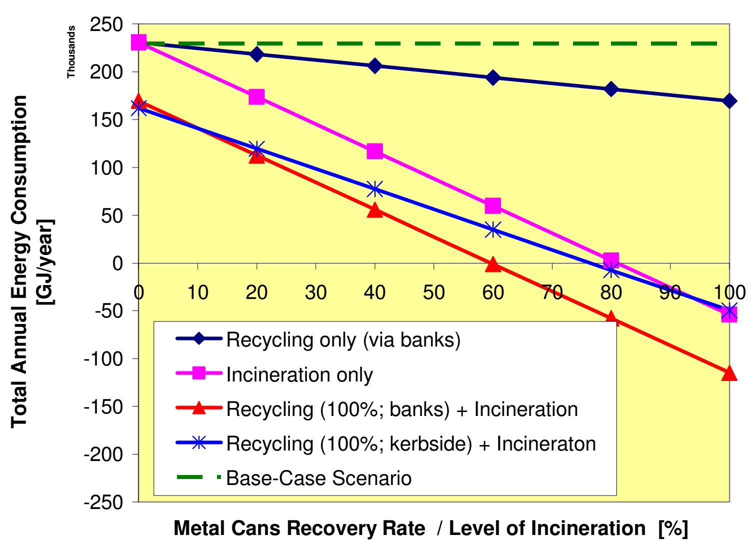


Figure 3.40: Comparison of Recycling and Incineration (Metals Fraction)

The affect that recycling of the metal cans has on the CV of the residual waste is shown in Figure 3.41. The graph shows that the CV varies according to the type of recycling method. For recycling via banks the CV increases with an increase in recycling because the metal cans

have (effectively) a zero CV, so removing them from the residual waste stream will increase its CV. The increase is, however, small and not significant (~ 2.8 % compared to the value at 0 % recycling rate).
Conversely, there is an increase in the CV with recycling via the dry recyclables scheme, although the change is even less significant (~ 0.3 %). This is because the kerbside scheme removes three types of material, each if which serves to counteract the effect on the CV of the other, as has been discussed in section 3.2.4. Again, the CVs at zero recycling rate are not the same for recycling via different methods. This is because, when the recycling rate is zero for recycling via the cans banks only metal cans are diverted back into the residual waste stream. With recycling the dry recyclables scheme, however, not only are the metal cans diverted back but also newspapers/magazines and plastic bottles/containers. Thus, the composition at zero recycling is different for the two collection methods.

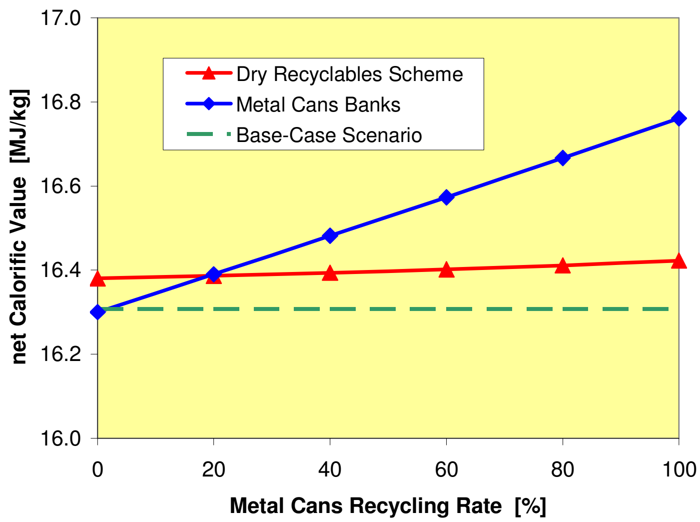


Figure 3.41: Effect of Recycling on Calorific Value of Residual Waste (Metals Fraction)

3.5 ORGANICS FRACTION

Although there are several different sub-categories of the organics waste fraction that are recyclable, only scenarios involving recycling of the putrescible fraction are considered in this report. In particular, recycling of garden waste through both centralised and home composting is examined.

The Energy Footprint model will be expanded in phase two of the project to include recycling of the other organic material, and examine other options for processing material within the organics fraction.

3.5.1 Energy Consumption of Waste Chain/Cycle Components

Figures 3.42 and 3.43 show the effect that recycling of the garden waste has on the energy consumption of the different stages of the waste chain/cycle associated with the recycling, processing and disposal of the garden waste fraction. In this scenario it is assumed that a fixed portion of the garden waste is collected via the kerbside garden waste (trial) scheme. The amount recycled is 304.52 tonnes/year, the base-case level, compared to 1238.65 tonnes via the HWRC site. In addition, it is assumed that the proportion of the population covered by the kerbside scheme is also fixed at the base-case level (~ 2.6 %). The recovery rate of material for the kerbside scheme is estimated to be ~ 91.6 % for the base-case scenario. This is based, however, on the average amount of garden waste generated by households in the whole of Southampton. Hence, it is likely to be somewhat less in reality, given the type of households served by the trial scheme (see section 2.6.3.1)**.**

The garden waste recycling rate is then varied by increasing the amount of material recovered via the HWRC site, for the proportion of the population not covered by the kerbside scheme (~ 97.4 %). This gives a maximum garden waste recycling rate of 99.78 % for 100 % recovery of the remaining material via the HWRC site.

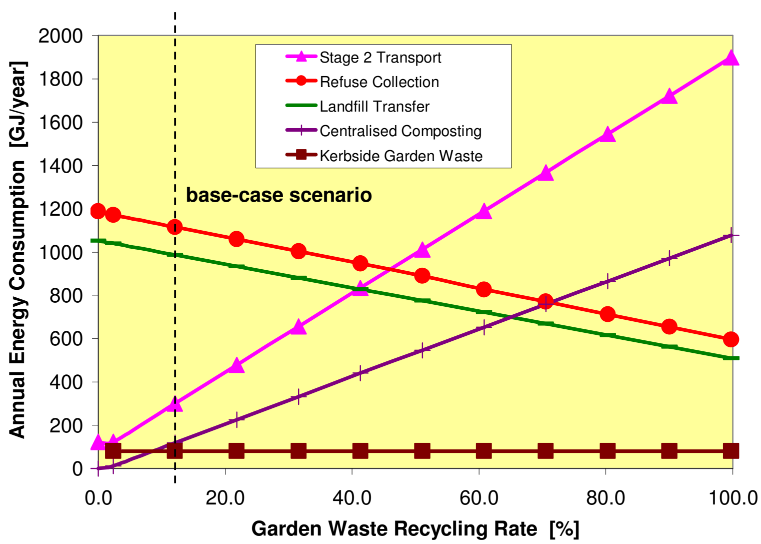


Figure 3.42: Effect of Garden Waste Recycling Rate on Energy Consumption (minor components)

It can be seen from both figures that there is a linear increase in the energy consumption associated with the recycling (collection, processing and transfer) stages. This is simply because, as more garden waste is recycled, more trips and collections, etc., are required (for a fixed site density) to transfer this material from point A to point B. Similarly, energy consumption associated with the disposal of the residual waste stream decreases (linearly), since less material requires disposal.

It can also be seen (Figure 3.43) that, firstly, the energy consumption for stage 1 transport (household to HWRC) is the dominant component, accounting for the vast majority of the total energy consumed. Secondly, the total energy consumption actually increases as the recycling rate is increased, which is in contrast to the trend found for the other waste fractions. This is because, unlike these other waste fractions, there is no processing/manufacturing component associated with the garden waste. The model presently does not consider any savings in energy consumption through replacement of traditional composting products with compost made from garden waste, although this area of the model will be expanded in the second phase of the Energy Footprint project. It is suffice to say, however, that it would be expected that savings would be made with respect to transport of the traditional compost products. It remains to be seen, however, whether these savings would be sufficient to offset the increase in energy consumption elsewhere.

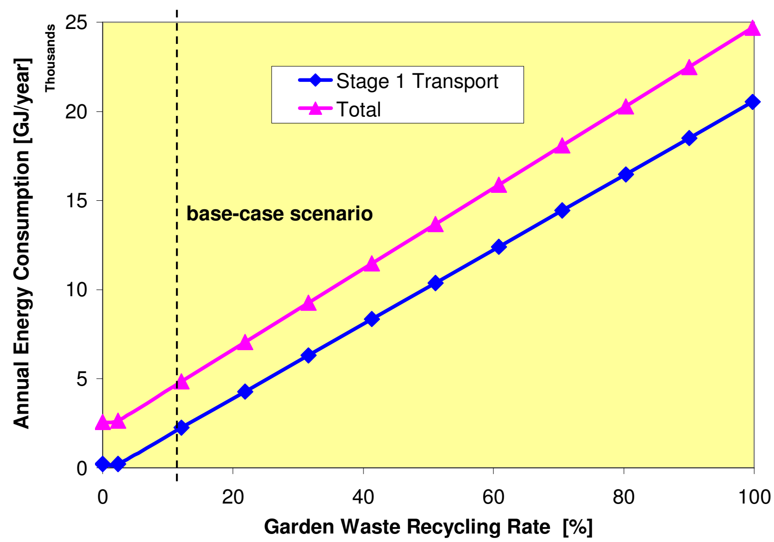


Figure 3.43: Effect of Garden Waste Recycling Rate on Energy Consumption (major components)

The results show that there is an approximately five - fold increase in energy consumption at maximum recovery rate (100 %) of garden waste via the HWRC (~ 52 % overall organics recycling rate), when compared to the base-case scenario (garden waste recovery rate of ~ 12 %), or an approximately 9.5 - fold increase compared to no recycling at all.

3.5.2 Recycling/Collection Method

Three different recycling/collection methods are presently considered in the energy footprint model: collection via the HWRC site; kerbside collection; and home composting. Comparison of the total energy consumption for each method is shown in Figure 3.44. The results are plotted in terms of the putrescibles fraction recycling rate, since home composting also includes recycling of the kitchen compostable sub-category.

The results show that recycling via the HWRC site consumes the most energy, mainly because of the large number of transfer-miles associated with this method of recycling: 250 miles/tonne garden waste transferred, compared to only 9.88 miles/tonne collected for the kerbside scheme. It is also due, to a certain extent, to the large amount of transfer-miles associated with the "gate-rejected" material for recycling via the HWRC site, because a "virtual" truck capacity of ~ 5.2 tonnes has been used, compared to a 20 tonne capacity for transfer of the compost product, etc. The virtual truck capacity is determined from the actual amounts of material transferred and the number of trips associated with this, for the base-case scenario.

In addition, the amount of reject material for recycling via the HWRC is higher than would be expected. This is because the gate-rejection rate (~ 22.7 %) that is presently used in the model is a somewhat spurious value: it is correct for the period covered by the base-case scenario, but is higher than normal because there were site odour problems at this time. Hence, the energy consumption using a more realistic rejection rate will be somewhat lower. This issue will also be addressed in future developments of the model.

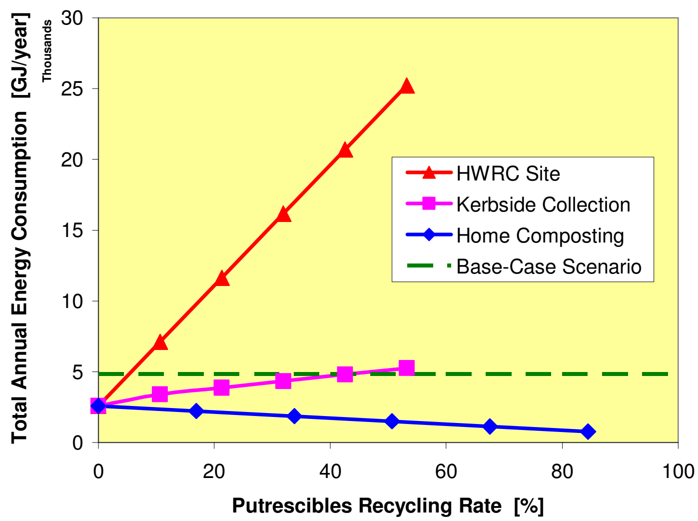


Figure 3.44: Effect of Recycling/Collection Method on Energy Consumption (Organics Fraction)

In addition, Figure 3.44 also shows that home composting consumes the least energy. Indeed, in contrast to the other recycling methods, the energy consumption decreases as more material is used for home composting. This is simply because there is no energy consumption associated with home composting, since no material is transferred or collected from the household to elsewhere. In addition, home composting removes more material from the residual waste stream, since it also recycles the kitchen compostable sub-category. Hence, there will be less energy consumption for the refuse collection and landfill transfer components associated with the organics waste fraction.

For recycling via kerbside collection there is an approximately 9 % increase in energy consumption at maximum recycling when compared to the base-case scenario (~ two-fold increase when compared to zero recycling). With home composting, the decrease in energy consumption is ~ 84 % compared to the base-case scenario (~ 71 % compared to zero recycling).

Two other scenarios have been examined here: the progressive replacement of recycling of the garden waste material at the HWRC site with recycling via the garden waste kerbside collection scheme (Figure 3.45); and the progressive replacement of the kerbside scheme with home composting (Figure 3.46).

The first scenario (Figure 3.45) starts from the position where there is only recycling via the HWRC site (kerbside coverage = 0 %). The recovery rate for this recycling method is fixed and assumed to be the same as the base-case scenario level (~ 9.9 %, taking into account the proportion of the population assumed to use the HWRC site - ~ 97.4 %). The amount of material recycled with zero kerbside coverage is also assumed to be the same amount as for the base-case scenario for the HWRC site (1238.65 tonnes).
The proportion of the population covered by the kerbside scheme is then increased, and the total energy consumption determined for different recovery rates. As the proportion is increased, the amount of material recycled via the HWRC site is decreased according to equation (11).
The results show that the total energy consumption (at a fixed kerbside coverage) increases as the kerbside recovery rate is increased, since more material is consumed for the transfer, etc., of the recycled material. For a given kerbside recovery rate the energy consumption does, however, generally decrease as the proportion covered by the kerbside scheme is increased, since the energy consumption associated with the kerbside collection method is less than recycling via the HWRC site. But, at recovery rates greater than ~ 80 % the energy consumption increases as the coverage increases, because more material is progressively recycled (at a given recovery rate) than for the zero coverage scenario.

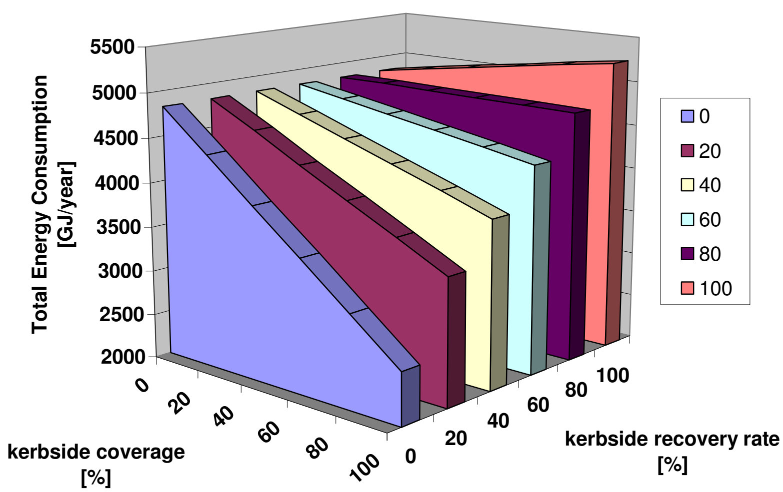


Figure 3.45: Replacement of Recycling of Garden Waste via the HWRC with Kerbside Scheme

The second scenario (Figure 3.46) looks at the progressive replacement of the kerbside garden waste scheme with home composting. The scenario assumes that the recovery rates of material from the garden waste kerbside scheme and home composting (which also includes recycling of the kitchen compostable material) are the same. Then, the proportion of the population covered by the kerbside scheme is varied. Also, the amount of material collected via the HWRC site has been set to zero throughout.
The results show that, for a given recovery rate, the energy consumption decreases as the kerbside coverage decreases, since more material is progressively being diverted from kerbside collection and into home composting. Also, below a kerbside coverage level of ~ 20 %, the energy consumption decreases as the recovery rate is increased. Here, sufficient material is being diverted for home composting to offset the energy consumption required to transfer and process the material collected from the kerbside scheme.

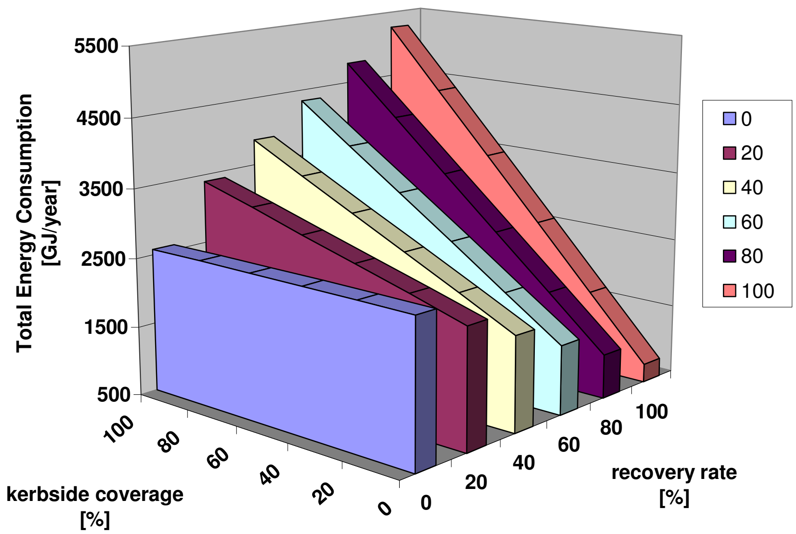


Figure 3.46: Replacement of Recycling via the Kerbside Garden Waste Scheme with Home Composting

Above ~ 40 % coverage, however, the energy consumption increases as the recovery rate is increased. Here, the amount of material diverted is not sufficient to offset the energy consumption associated with the recycling of the remainder of the material via the kerbside scheme. And, finally, between ~ 20 – 40 % coverage there is a transition period where the energy consumption switches from decreasing to increasing as the recovery rate is increased (when compared to zero recovery rate). This is simply because there is a point (particular kerbside coverage level) where there is a balance of the energy savings through diversion to home composting and energy consumed from recycling via the kerbside.

3.5.3 Incineration

The effect that incineration has on the total energy consumption has been examined by comparing the base-case scenario with the following other scenarios:

1) recycling of the garden waste via the HWRC site with variable recovery rate, and landfill of the residual waste stream
2) no recycling of the garden waste, and variation of the level of incineration of the residual waste stream (with landfill of the remainder)
3) recycling of the garden waste via the HWRC site with a 100 % recovery rate and variable levels of incineration
4) recycling via the garden waste kerbside scheme (100 % recovery rate) and variable levels of incineration

Firstly, the results (Figure 3.47) show that whilst recycling of the garden waste with landfill of the residual waste stream leads to an increase in the total energy consumption, incineration without recycling gives a large reduction in energy consumption. In addition, the combination of recycling, both via the HWRC site and the kerbside scheme, together with incineration of the residual waste stream (scenarios 3 and 4) gives a higher energy consumption than just incineration (scenario 2). This is because, firstly, recycling increases the energy consumption associated with the recycling components of the waste chain/cycle. In addition, recycling reduces the amount of material that is sent for incineration, resulting in a lower amount of energy produced from incineration.

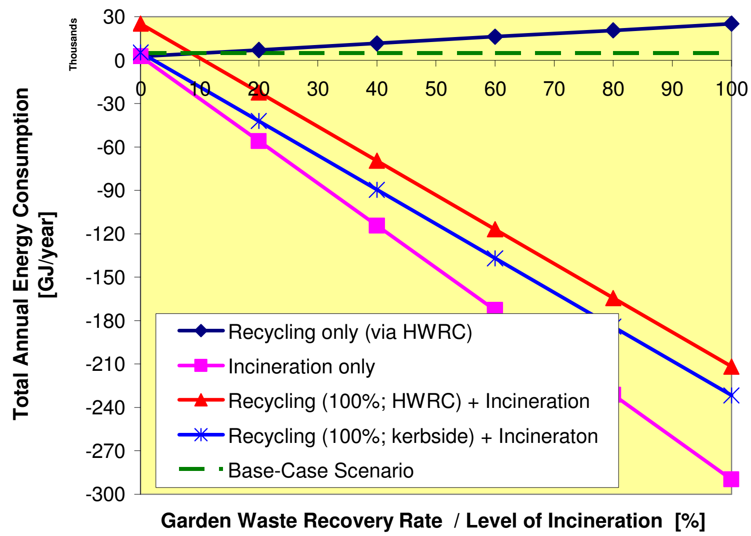


Figure 3.47: Comparison of Recycling and Incineration (Organics Fraction)

Although not plotted on the graph, the scenario of home composting (100 %) together with incineration gives a similar level of energy consumption as scenario 4. This is because, although the energy consumption through recycling is much less for home composting, the energy produced from incineration is also less since home composting diverts more material from the residual waste stream. Thus, the two effects counteract each other in a similar manner as in scenario 4.

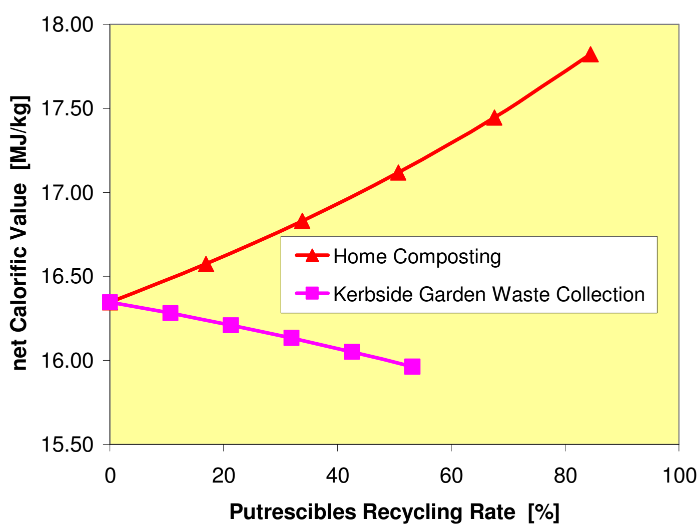


Figure 3.48: Effect of Recycling on Calorific Value of Residual Waste (Organics Fraction)

As well as recycling affecting the amount of residual waste available for incineration, it also has an effect on the CV of the residual waste (Figure 3.48). The graph shows that the CV varies according to the type of recycling method. For recycling of the garden waste via the kerbside collection scheme (and HWRC site, since the amount of material recycled is the same) the CV decreases with an increase in recycling because the garden waste has a relatively high CV (when compared to the bulk CV of the refuse as a whole), so removing this material from the residual waste stream will reduce its CV. The reduction is, however, small and not significant (~ 2.4 % compared to the value at 0 % recycling rate).

In contrast, when material is diverted for home composting the CV increases and this is more significant (~ 9 % at maximum recycling, when compared to zero recycling rate). This is because of the low CV of the kitchen compostable material, mainly because of its high moisture content.

3.6 GLOBAL WASTE MANAGEMENT AND COMPARISON OF WASTE FRACTIONS

In this section various "global" waste management scenarios, where the different waste fractions are recycled collectively, are highlighted. These essentially give the energy consumption for the management of waste within Southampton under various different recycling, etc., conditions.
Comparison is also made of the energy consumption associated with the recycling of the individual waste fractions. This serves to highlight which materials provide the greatest energy savings for a given scenario.

3.6.1 Global Waste Management

In previous sections the energy consumption for the management of the five main waste fractions was determined in isolation for various scenarios. Here, however, recycling of all five waste fractions collectively is considered for various scenarios (Figure 3.49). For the scenarios shown, recycling of the different waste fractions is generally as described for the individual materials, with some slight changes, and is as follows:

- **Glass**: recycling is via bottle banks located at bring-sites and the HWRC, as discussed in section 3.1.1, with variable recovery rate.
- **Paper/card**: the amount of material recycled via the paper/card banks is kept fixed at the base-case scenario level; the recovery rate of the newspaper and magazines sub-categories only is then varied through recycling via the PaperChain scheme (section 3.2.1). At zero recovery rate the amount for all the paper/card sub-categories is set to zero (i.e. paper/card banks tonnes set to zero).
- **Plastics**: recycling is via plastics banks located at bring-sites and the HWRC (section 3.3.1), with variable recovery rate.
- **Metals**: recycling of the metal cans only is varied, through changes in the recovery rate of these via mixed metal cans banks (3.4.1). The amount of material recycled for the other sub-categories of metal is kept fixed throughout at the base-case scenario level.
- **Organics**: recycling of the garden waste sub-category only is varied. The amount of other sub-categories of the organics waste fraction is kept fixed at the base-case level (section 3.5.1). In addition, the amount of material recycled via the kerbside garden waste scheme is also kept fixed at the base-case level, and the recovery rate via the HWRC site then varied. At zero recovery rate the amount of garden waste collected via the kerbside scheme is also set to zero. Conversely, at 100 % recovery rate, the recovery rate for the material via the kerbside scheme is set to 100 % in order to give an overall recovery rate of 100 % for the garden waste sub-category.

3.6.1.1 Recycling versus Incineration

Recycling of the five waste fractions is then varied collectively, with the amount of material recycled being varied accordingly in order to give the same recovery rate for each waste fraction. Hence, the scenario looks at an "across-the-board" variation in the recovery rate of glass, newspapers and magazines, plastic bottles/containers, metal cans, and garden waste. The energy consumption associated with the recycling and processing/manufacture of each waste fraction is then determined, and summed to give the total for this. The energy consumption for the disposal of the residual waste stream (**<u>all</u>** waste fractions) is then added to this value in order to give the total 'global' energy consumption, and show the effect that recycling has on this. The global energy consumption for the following four different scenarios are considered, and compared to the base-case scenario:

1) Recycling only (as described above), with landfill of the residual waste stream
2) No recycling of the waste materials detailed above, and variable levels of incineration of the residual waste stream, with landfill of the remainder
3) Recycling at the base-case levels, with variable levels of incineration of the residual waste stream
4) Recycling with maximum recovery of the waste materials detailed above, with variable levels of incineration of the residual waste stream

Figure 3.49 shows similar trends as found for the individual waste fractions. For recycling only, there are energy savings of ~ 9.6 % at the maximum recovery rate, when compared to the base-case scenario. As before, the energy consumption with incineration-only is significantly lower than the scenario with recycling-only: there are savings of 30 % compared to the base-case scenario, and ~ 22.6 % when compared to the recycling scenario at maximum recovery.
The energy consumption for scenario 3 (base-case recycling plus incineration) is somewhat lower than scenario 2 (incineration-only) for levels of incineration less than approximately 60 %. At about 70 % there is, however, a cross-over point where the energy consumption becomes slightly more for scenario 3. The reason is as before (for the individual waste fractions): at low levels of incineration, the savings in energy consumption through recycling is dominant; conversely, at high levels of incineration these savings are offset by a decrease in the amount of energy produced through incineration, due to a reduction in the amount of residual waste available for incineration.

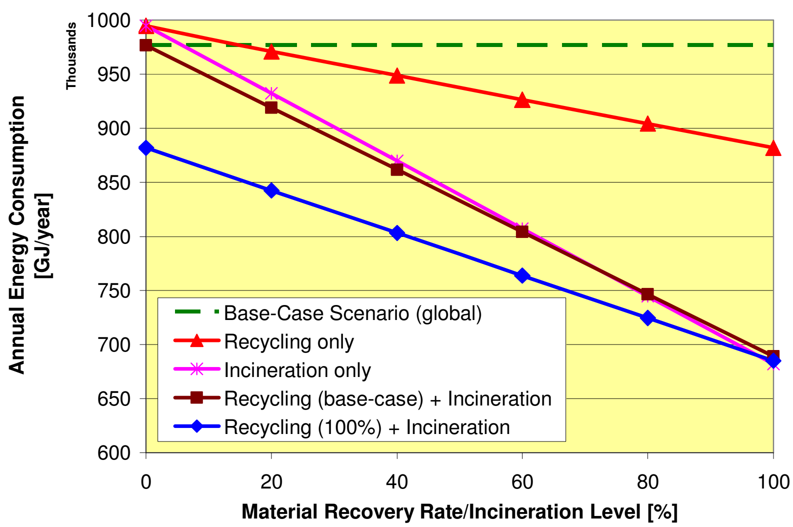


Figure 3.49: Energy Consumption for Global Waste Management Options

With maximum recycling combined with incineration of the residual waste stream (scenario 4), the energy consumption is lower than scenario 2 for all levels of incineration, although there is convergence as the level of incineration is increased. Again, the reasons are the same: dominance of the energy savings made through recycling, that are progressively diminished as the level of incineration is increased.

The results would suggest that if high levels of incineration are employed as part of the waste management strategy for Southampton, then in order to achieve minimum energy consumption it would not be necessary to recycle any of the materials detailed here, particularly at base-case levels of recycling. Conversely, with lower levels of incineration of the residual waste stream it is better to recycle as much as possible in order to minimise the global energy consumption.
It should, however, be noted that there might be other scenarios that would give a lower global energy consumption. For example, maximum recycling of one particular waste fraction, but no recycling of another waste fraction. This will be examined in phase two of the project.

3.6.1.2 Standard Recycling versus Dry Recyclables Scheme

In terms of annual energy consumption for global waste management it can be seen (Figure 3.50) that recycling via the dry recyclables kerbside scheme gives a lower energy consumption than recycling via the methods used for the base-case scenario ("standard" methods). Here, comparison is made between the following four scenarios:

1) Recycling of paper/card via banks at base-case levels, plus variable recovery of material via the PaperChain scheme, together with variable recovery of material via plastic/metal cans banks; recycling of all other materials is at the base-case level
2) Recycling of paper/card, plastic bottles/containers, and metal cans via the dry recyclables scheme only with variable recovery; recycling of all other materials is at the base-case level
3) No recycling of the dry recyclable materials, and variable levels of incineration of the residual waste stream, with landfill of the remainder; recycling of all other materials is at the base-case level
4) Recycling with maximum recovery of the dry recyclable materials, with variable levels of incineration of the residual waste stream; recycling of all other materials is at the base-case level

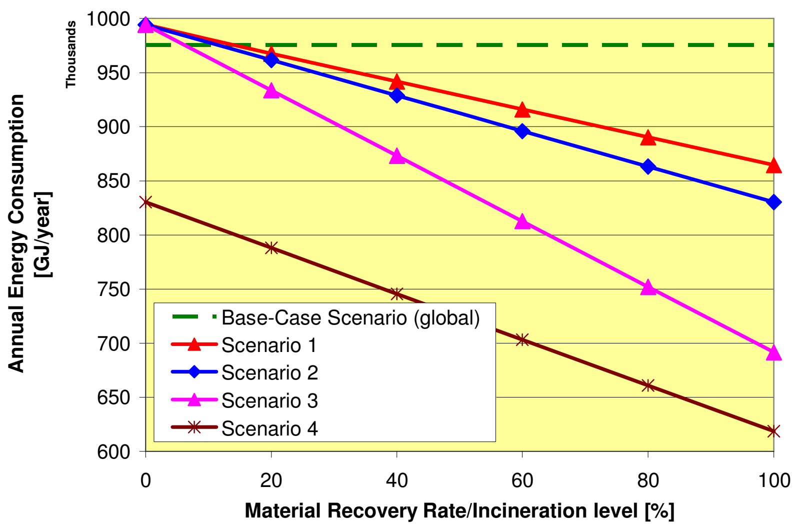


Figure 3.50: Comparison of Global Energy Consumption for Standard Recycling and Recycling via the Dry Recyclables Scheme

The results show that, compared to the base-case scenario, maximum recovery via the dry recyclables scheme (scenario 2) results in savings of ~ 14.9 % for the global energy consumption. For recycling via the standard methods the savings are only ~ 11.4 % (scenario 2; cf. 9.6 % in section 3.6.1.1 for recycling of all five waste fractions). As before, though, the scenario with incineration (3) only gives a lower energy consumption than both these other scenarios: savings of ~ 29.1 % at maximum levels of incineration, when compared to the base-case scenario. But, once more, the scenario with a combination of maximum recovery of material (here dry recyclables) with incineration of the residual waste stream (4), gives the least energy consumption (savings of ~ 36.6 %). This scenario also gives a lower energy consumption than the corresponding scenario with recycling via the standard methods (see Figure 3.49). Indeed, there is no convergence with the incineration-only scenario at high levels of incineration, as was seen with recycling via the standard methods.

3.6.2 Comparison of other Recycling Methods

In previous sections, comparison of the different recycling methods for the individual waste fractions was made. Here, the results are collated to allow comparison of the different waste fractions, as shown in Tables 3.1 and 3.2 (and Table E1 in the Appendix).

Table 3.1 shows that for recycling at bring-sites the glass fraction consumes the least energy per tonne of material recycled (0.18 GJ/tonne). This compares to ~ 5.6 GJ/tonne for recycling of the plastic bottles/containers. The more detailed breakdown of the results (Table E1) show that the energy consumption is dependent on several factors, but mainly the number of bring-sites and the amount transferred per bring-site, since these both influence the total transfer miles travelled. For glass, there is a relatively high site density (86 sites), which gives a relatively low transfer distance and proportion of trips made specifically for recycling. Hence, this gives, overall, a low energy consumption per tonne transferred.

	bring-site	**HWRC**
Glass:		
number of sites	86	1
transfer-miles/tonne	16.49	250
Energy Consumption [GJ/tonne]	0.180	1.695
Paper & card:		
number of sites	22	1
transfer-miles/tonne	41.56	250
Energy Consumption [GJ/tonne]	0.339	1.688
Plastics:		
number of sites	5	1
transfer-miles/tonne	555.59	250
Energy Consumption [GJ/tonne]	5.593	3.433
Metals:		
number of sites	5	1
transfer-miles/tonne	92.60	250
Energy Consumption [GJ/tonne]	3.410	9.872
Organics:		
number of sites	-	1
transfer-miles/tonne	-	250
Energy Consumption [GJ/tonne]	-	1.762

Table 3.1: Comparison of Recycling at Bring-Sites and HWRC (Base-Case Scenario)

For paper (only recycling of paper is considered here, since no card is recycled via bring-sites), the energy consumption per tonne is approximately twice that for glass. This is mainly due to the fact that the site density is lower (22 sites), giving a greater transfer distance, etc. Also, the distance from the bring-site to the next stage (here, the WTS) is greater than for glass. It should be noted, however, that direct comparison of this stage of the transfer cannot be made: for glass this stage is direct transfer to the processing plant, whereas for paper it is to an intermediate point (WTS). The overall energy consumption associated with recycling is, however, discussed in more detail in section 3.6.3.

There is a significant increase in the energy consumption per tonne for recycling of the plastic bottles/containers via bring-sites. As mentioned, to a certain extent, this is due to the low number of bring-sites (5), giving rise to a greater transfer distance, etc. The main reason, however, is the decrease in the amount of material taken to the bring-site per trip (0.75 kg) due to the low weight-to-volume ratio of the plastic bottles/containers.

The greater energy consumption for the metal cans when compared to that for glass/paper is mainly due, however, to the greater transfer distance from the bring-sites to the next stage. Here, this is direct to the MDR-MRF facility for sorting.

With recycling via the HWRC the energy consumption per tonne material recycled is similar for the glass, paper, and garden waste materials. This is mainly because the majority of the energy consumption (more than 90 %) for these materials is associated with transfer to the HWRC (stage 1 transport), which is constant for every material, since it is assumed that all the materials are taken together to the HWRC.

For the plastics and metal cans, however, the stage 1 transport makes up only ~ 47 % and 16 %, respectively, of the total energy per tonne transferred, with the remainder being associated with the stage 2 transport phase. Hence, the total energy consumption will be higher than for the other materials. The main reason for this is the fact that the amount of material transferred from the HWRC per collection (see Table E1) is more than a factor of ten lower for the plastics/metal cans than it is for the other materials. Hence, more collections are needed per tonne, which requires a greater energy consumption.

Similarly, comparison of recycling via different collection methods for paper and garden waste shows (Table 3.2) that for both these materials that the energy consumption per tonne is lower for collection via the kerbside than for recycling via the other methods. In addition, the values for the PaperChain scheme and the kerbside garden waste scheme are almost the same. This is because both the amount of material transferred per collection (2.90 tonnes for the PaperChain scheme; 3.27 tonnes for kerbside garden waste collection), and the transfer-miles per collection (~ 25.3 miles for the PaperChain scheme; ~ 32.6 miles for the garden waste scheme) are of similar magnitude.

	Paper			Garden Waste	
	PaperChain	bring-site	HWRC	kerbside	HWRC
tonnes transferred	3194	776.93	110.16	304.52	1238.65
transfer-miles	28079	34092	27790	3029	315807
transfer-miles/tonne	8.79	43.88	252.27	9.95	254.96
Energy Consumption [GJ/year]	835.78	263.70	185.94	80.53	2182.82
Energy Consumption [GJ/tonne]	0.262	0.339	1.688	0.264	1.762

Table 3.2: Comparison of Recycling at Bring-Sites/HWRC and Kerbside (Base-Case Scenario)

3.6.3 E-Factors

It is difficult to compare the effects of recycling on the total energy consumption for the management of the individual waste fractions, since the magnitude of each can be very different. For instance, the total energy consumption associated with the paper/card fraction for the base-case scenario is approximately 641,000 GJ/year, whereas it is only approximately 4800 GJ/year for the organics fraction. Therefore, the data has been expressed here in terms of an Energy Factor ("E-factor"). This is the ratio of the energy consumption at a given recovery rate (or other parameter, e.g. level of incineration of the residual waste stream) to the energy consumption for the base-case scenario. Hence, the base-case scenario has an E-factor of ONE, with a value below this indicating a decrease in energy consumption, and a value above indicating an increase (when compared to the base-case scenario).

The results, Figure 3.51, show that for all waste fractions except organics the E-factors are less than one for recovery rates greater than the base-case level. For the organics the E-factor shows, however, that there is a five-fold increase in energy consumption at maximum recovery (of the garden waste fraction).

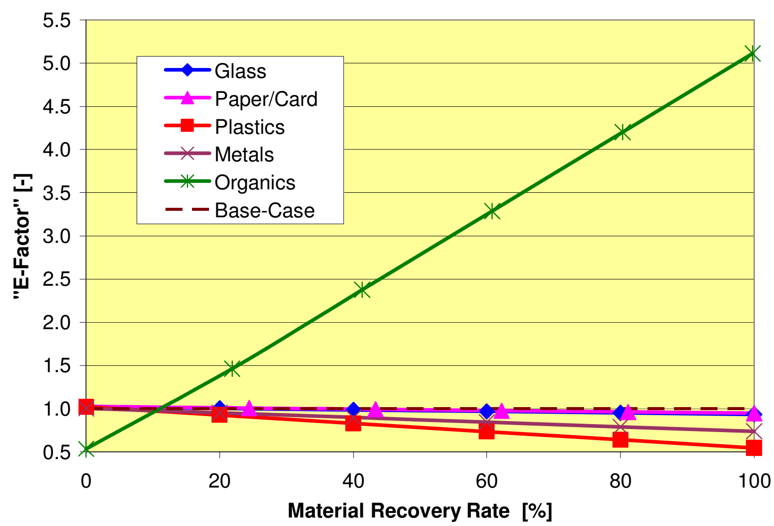


Figure 3.51: Comparison of E-Factors for Recycling of Different Waste Fractions (1)

It can also be seen from Figure 3.51 that all the waste fractions except organics have E-Factors of similar magnitude. Therefore, these have been re-plotted in Figure 3.52 so they can be compared more readily. It can be seen from the graph that the E-factors for glass and paper/card are not reduced much by recycling: ~ 6.6 % and ~ 5.1 %**,** respectively, at maximum recovery (of glass and newspapers/magazines, respectively). In contrast, the E-factors for the plastics and metals fractions are significantly higher: ~ 45.5 % for the plastics (maximum recovery of bottles/containers), and ~ 26.2 % for the metals (maximum recovery of metal cans).

Although use of the E-factors allows comparison of the savings made through recycling of the different waste fractions, it does not indicate the absolute savings made through recycling. These are shown in Table 3.3, and Table E2 in the Appendix, which also gives details of the energy consumption for the different phases of the waste chain/cycle, and the savings/increases per tonne material recycled. The results given are for recycling via the collection methods indicated in section 3.6.1.

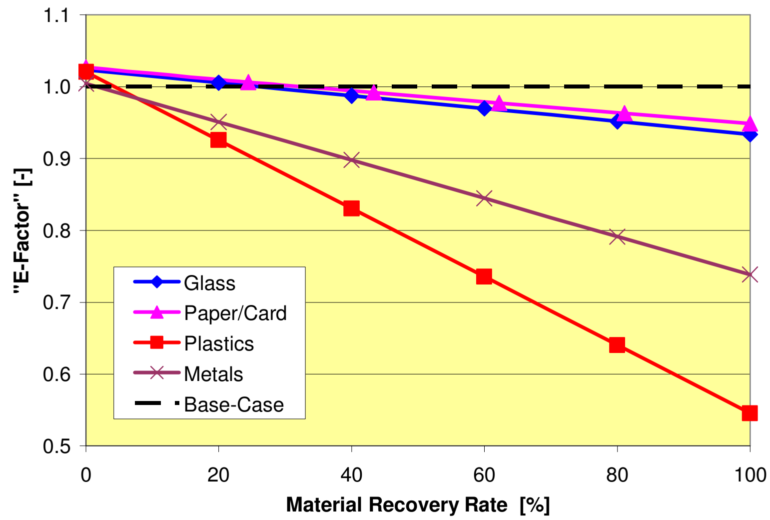


Figure 3.52: Comparison of E-Factors for Recycling of Different Waste Fractions (2)

The Table shows that, for instance, although the reduction in the E-factor with recycling for the paper/card fraction is small, the absolute savings in energy consumption is relatively large (~ 33,000 GJ/year) when compared to the other waste fractions. For plastics, the E-factor is relatively low at maximum recycling but the absolute energy savings are also low. Conversely, for metals, the E-Factor is low and the energy savings are high. The trends that are seen in the absolute energy savings are also found for the savings per tonne of material recycled (given in Table E2), expressed in terms of savings per additional tonne of material recycled, compared to the amount of material recycled for the base-case scenario.

Material	**Total Energy Consumption [GJ/year]**			
	base-case	**max. recovery**	**Difference**	**E-Factor**
Glass	60454	56455	4000	0.93
Paper & card	640943	608064	32879	0.95
Plastics	39609	21595	18015	0.55
Metals	229710	169614	60096	0.74
Organics	4831	24694	-19863	5.11
TOTAL	**975547**	**880422**	**95125**	**0.90**

Table 3.3: Absolute Energy Savings for Different Waste Fractions

3.6.4 Recycling Rate

Details are given here of the effect that recycling of the different materials detailed in the previous section has on the recycling rate of the different waste fractions, and on the overall household waste recycling rate (HWRR). Here, the HWRR is defined as the ratio of the amount of material (waste) recycled to the amount of household waste generated (Table B1).
Table 3.4 shows how the recycling rate of each of the different waste fractions changes with variation of the recovery rate of the specified materials within each waste fraction (glass, newspapers/magazines, plastic bottles/containers, metal cans, and garden waste). For instance, with glass a 100 % recovery rate gives almost as high a recycling rate, since the majority of the glass waste fraction is considered recyclable. At the opposite end of the

spectrum is the plastics fraction, where maximum recovery of the (presently; either actual or assumed) recycled plastics material equates to little more than a 10 % overall plastics recycling rate. As detailed in section 3.3**,** this is because only the plastic bottles/containers are assumed to be recyclable, and these only make up a small part of the plastics waste fraction. For the other waste fractions maximum recovery gives recycling rates of between 50 – 70 %.
If collective recycling of all five waste fractions is considered (column "ALL" in Table 3.4), then maximum recovery of the specified materials detailed above gives a combined recycling rate of approximately 50 %. That is, ~ 50 % of the five waste fractions as a whole could be recycled when there is maximum recovery of the specified materials as described above. If the amount is expressed in terms of the overall household waste recycling rate, then maximum recovery of all the specified waste materials alone leads to a recycling rate of approximately 38.5 % for all the household waste.

recovery rate:	**Recycling Rates**						
	Glass	**Paper & Card**	**Plastics**	**Metals**	**Organics**	**ALL**	**Overall HWRR**
base-case	25.84	18.10	0.46	23.46	6.72	12.07	9.35
0	0.00	0.00	0.00	22.73	0.55	1.71	1.32
20	19.72	11.73	2.10	31.90	10.84	11.76	9.12
40	39.43	21.67	4.19	41.07	21.13	21.22	16.44
60	59.15	31.60	6.29	50.24	31.42	30.67	23.77
80	78.87	41.53	8.38	59.41	41.71	40.12	31.10
100	98.59	51.47	10.48	68.58	52.01	49.58	38.43

Table 3.4: Effect of Material Recovery Rate on Recycling Rate

In addition, Table 3.5 compares the effect that recycling of the individual waste fractions, in the same manner as detailed above, has on the overall HWRR. Here, the recovery rate of a particular waste fraction (material) is varied, whilst the amount recycled for all other waste material (see Table B1) is kept fixed at the base-case level (cf overall HWRR given in Table 3.4, where these are set to zero). In order to determine the HWRR for the base-case scenario, it has been assumed that all material taken to the HWRC except the "amenity" (general waste) material is recycled.
The results in the Table highlight which material, when recycled or not, has the greatest impact (positive or negative) on the overall HWRR for Southampton. For instance, because the amount of plastic bottles/containers and metal cans presently recycled is so small, there would be little impact on the HWRR, when compared to the base-case rate, if recycling of either (or both) material was discontinued. Similarly, maximum recovery of these materials only increases the HWRR slightly, since they make up only a small part of the generated household waste: ~ 1.4 % and ~ 2.4 %, respectively (note: this is on a weight basis).
Conversely, recycling of newspapers/magazines, and garden waste both have the greatest impact on the overall recycling rate for Southampton because they both make up a significant proportion of the generated household waste: ~ 12.9 % and ~ 14.2 %, respectively.
If maximum recovery of all of the materials detailed above is achieved collectively, then this would give an overall HWRR of approximately 40 %. Considering recycling via the dry recyclables scheme only (with base-case levels of recycling for all other materials) achieves an overall recycling rate of ~ 32 %, at maximum recovery of the dry recyclables. This is mainly because the paper/card sub-categories that are recycled via the kerbside scheme make up ~ 22.7 % of the total household waste generated.
In addition, if recycling of the dry recyclables is combined with recycling of the glass and garden waste materials, then this would give an overall HWRR of ~ 49 % with maximum

recovery. This compares to only ~ 40 % for recovery via the standard recycling/collection methods for the paper/card, plastics and metals waste fractions (together with recycling of the glass and garden waste materials).

	Overall Household Waste Recycling Rate:						
Recovery rate:	**glass**	**paper/ card**	**plastics**	**metals**	**organics**	**ALL**	**Dry Recyclables only**
base-case		10.59					
0	9.07	5.88	10.53	10.56	8.89	2.56	5.79
20	10.23	8.94	10.80	11.03	11.73	10.36	11.08
40	11.39	11.52	11.07	11.50	14.57	17.68	16.36
60	12.55	14.10	11.34	11.97	17.41	25.01	21.65
80	13.71	16.69	11.61	12.45	20.25	32.34	26.94
100	14.87	19.27	11.88	12.92	23.09	39.67	32.23

Table 3.5: Effect of Material Recovery Rate on Household Waste Recycling Rate

3.6.5 Refuse Generation and Composition

The effect that recycling of the individual waste fractions separately and collectively has on the amount of refuse generated and its composition is shown in Table 3.6. An expanded version of this Table is given in the Appendix (Table E3). It can be seen that recycling of the plastics (bottles/containers only) has the least impact (1.6 % decrease) on the amount of refuse (residual waste stream) generated, when compared to the base-case scenario. In contrast, maximum recycling of the garden waste gives rise to a 15.1 % reduction in the amount of refuse.

Waste Category	**Material Recycled**							
	Base- Case scenario	**glass**	**paper/ card**	**plastics**	**metals**	**garden waste**	**ALL**	**Dry Recyclables only**
	[wt %]	[wt %]	[wt %]	[wt %]	[wt %]	[wt %]	[wt %]	[wt %]
Paper & card	25.79	27.20	17.08	26.20	26.54	30.39	23.58	5.38
Plastic Film	8.90	9.38	9.94	9.04	9.16	10.49	13.73	12.06
Dense Plastic	6.59	6.95	7.36	5.11	6.78	7.76	7.76	6.81
Textiles	5.78	6.10	6.46	5.87	5.95	6.81	8.92	7.83
Misc. Comb.	6.99	7.37	7.81	7.10	7.19	8.23	10.78	9.47
Misc. non-Comb.	1.31	1.38	1.46	1.33	1.35	1.54	2.02	1.77
Glass	5.28	0.11	5.90	5.36	5.43	6.22	0.16	7.15
Ferrous Metals	3.67	3.87	4.10	3.73	1.24	4.32	1.86	1.63
non-ferrous metals	1.11	1.17	1.24	1.12	0.78	1.30	1.16	1.02
putrescibles	30.27	31.92	33.82	30.75	31.14	17.83	23.35	41.01
Fines	4.32	4.56	4.83	4.39	4.45	5.09	6.67	5.86
tonnes/year	**74815**	**70941**	**66954**	**73649**	**72709**	**63493**	**48485**	**55218**
kg/hh/week	**15.66**	**14.85**	**14.01**	**15.41**	**15.22**	**13.29**	**10.15**	**11.56**

Table 3.6: Effect of Recycling (maximum recovery) on Refuse Composition

Overall, maximum recovery of the glass, newspapers/magazines, plastic bottles/containers, metal cans, and garden waste, with base-case levels of recycling for all other materials, gives a reduction of approximately 35.2 % in the amount of refuse generated. If, however, recycling via the dry recyclables scheme with maximum recovery and base-case levels for all other materials is considered instead, then a reduction of ~ 26.2 % can be achieved.

		Calorific Value of Residual Waste Stream (Refuse) [GJ/tonne]:					
Recovery rate:	**glass**	**Paper /card**	**plastics**	**Metals**	**organics**	**ALL**	**Dry Recyclables only**
base-case		16.31					
0	16.02	16.38	16.32	16.30	16.35	16.14	16.38
20	16.24	16.34	16.27	16.39	16.28	16.28	16.39
40	16.46	16.29	16.21	16.48	16.21	16.44	16.39
60	16.70	16.24	16.16	16.57	16.13	16.64	16.40
80	16.94	16.19	16.11	16.67	16.05	16.89	16.41
100	17.19	16.14	16.06	16.76	15.96	17.20	16.42

Table 3.7: Effect of Material Recovery Rate on Calorific Value of Refuse

Also included in this section is a comparison of the effect that recycling of the individual waste fractions separately and collectively has on the calorific value of the residual waste stream (Table 3.7 Figure 3.53). Firstly, it can be seen that with no recycling of the individual waste fractions there is little change to the CV when compared to the base-case scenario value, except for recycling of the glass fraction. Maximum recovery of the glass fraction also gives the greatest change (increase) to the CV, although this only amounts to an increase of approximately 5.4 %. The greatest decrease in CV is achieved through maximum recycling of the garden waste material (organics fraction) although, again, the change is small (~ 2.1 %).

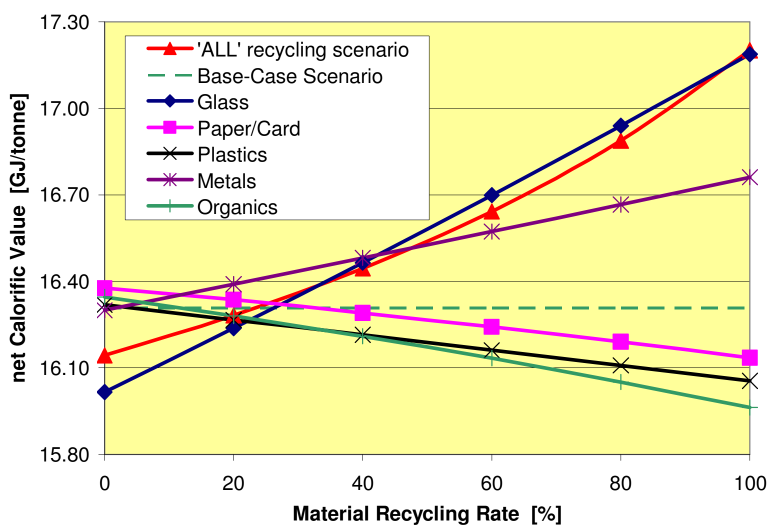


Figure 3.53: Comparison of Calorific Value of Refuse for Recycling of Different Waste Fractions

If recycling of all the materials collectively is considered then the change in CV with recovery rate is similar to that for the glass fraction. This is because this has the greatest impact on the CV and the change in CV for the other waste fractions tend to, effectively, cancel each other out. In addition, Table 3.7 also shows the effect that recycling via the dry recyclables scheme has on the CV of the residual waste stream (see section 3.2.4) and it can be seen that there is little effect on the CV.

It should be noted, as highlighted in section 2.2.9, that the CV is a theoretical value. Hence, any changes will be relative to this value, and it is possible that different trends will be found for a lower (bulk) CV for the refuse. This will be addressed in future developments of the model.

4 CONCLUSIONS

The general conclusions for the recycling, etc. of the different individual waste fractions are given here, together with conclusions for the various global waste management scenarios examined.

4.1 GLASS FRACTION

- The major source of energy savings from glass recycling is through increased use of the recycled material in the manufacturing process. Energy savings of 6.6 % can be achieved with maximum recycling via bottle banks, compared to the base-case scenario, and 8.8 % compared to zero recycling.
- Recycling via kerbside collection is better than via bring-sites, especially since it would be expected that the actual achievable recycling/recovery rates from kerbside schemes would be considerably higher than via bring-sites. Maximum energy savings using this method increase to 8.4%, compared to the base-case scenario.
- Although incineration is a favourable option for waste management, since it produces energy, it is not favourable to use it in place of glass recycling, but rather in combination with it. Glass is inert, so has limited effect on the energy produced from incineration. If cullet is used in the glass manufacturing process it does, however, have a marked effect on the energy required to produce glass.
- It is preferential to use recycled glass to make more glass, rather than as a replacement for aggregates. Whereas the energy consumption decreases as more recycled glass is used in glass manufacture, diversion of the glass to aggregates use increases the energy consumption as the amount of glass recycled is increased. At maximum diversion this increase amounts to 4.5%. Hence, there is no benefit, in terms of energy, in diverting recycled glass away from glass manufacture.

4.2 PAPER & CARD FRACTION

- The major source of energy savings from paper/card recycling is through increased use of recycled material in paper/card manufacture. There is a 4.9 – 8.7 % reduction in total energy consumption with maximum overall paper/card recycling rate when compared to the base-case scenario, depending on the method of collection of material for recycling. When compared to zero recycling, the range in savings is 7.4 % - 11.1 %.
- The dry recyclables kerbside collection scheme would be the preferred collection method of paper/card recycling, since it has the potential to recycle the most paper/card, leading to the greatest reduction (8.75%) in energy consumption compared to the base-case scenario.
- In terms of energy consumption, recycling of paper/card, with incineration of the residual waste stream, is generally the preferred waste management option, unless the levels of incineration are high.

4.3 PLASTICS FRACTION

- The major source of energy savings from plastics recycling is through increased use of the recycled material in the manufacturing process. Energy savings of 45.5 % can be achieved with maximum recycling, compared to the base-case scenario (46.6 % compared to zero recycling).

- Recycling via kerbside collection is better than via bring-sites, especially since it would be expected that the actual achievable recycling/recovery rates from kerbside schemes would be considerably higher than via bring-sites. Maximum energy savings using this method increase to 54.9 %, compared to the base-case scenario (55.8 % compared to zero recycling).
- Incineration of the residual waste stream has a lower energy "footprint" than recycling of the plastics combined with landfill of the residual waste. If recycling of the plastics is, however, combined with incineration, the energy consumption will be, to a certain extent, lower than incineration alone. For recycling via the plastics banks, this is true for all levels of incineration. With recycling via the dry recyclables scheme this is only true, however, at levels of incineration less than ~ 30 %. Indeed, it would become energetically unfavourable if more than ~ 30 % of the residual waste stream is incinerated. Hence, the choice of the best waste management option (in terms of the energy footprint) would be dependent on the collection method and the desired level of incineration of the residual waste stream.

4.4 METALS FRACTION

- The major source of energy savings from recycling of metal cans is through the increased use of the cans in the manufacturing process. Energy savings of 26.2 % can be achieved with maximum recycling, compared to the base-case scenario (26.5 % compared to zero recycling).
- Recycling via the dry recyclables scheme is better than via bring-sites, with maximum energy savings using this method increasing to 29.5 %, compared to the base-case scenario (29.8 % compared to zero recycling).
- Incineration of the residual waste stream consumes less energy than recycling of the metal cans combined with landfill of the residual waste. If recycling of the metal cans is, however, combined with incineration, then the energy consumption will generally be lower than with incineration alone. For recycling via the metal cans banks, this is true al all levels of incineration, although, with recycling via the dry recyclables scheme this is only true up to a level of ~ 95 % incineration. Above this level it becomes energetically unfavourable to combine recycling with incineration. Hence, the choice of the best waste management option would be dependent on the collection method and the desired level of incineration of the residual waste stream.

4.5 ORGANICS FRACTION

- There is an increase in energy consumption with increased recycling of garden waste. Indeed, there is an approximately five-fold increase in consumption with maximum recycling of garden waste via the HWRC, when compared to the base-case scenario (~9.5-fold when compared to zero recycling)
- Recycling via kerbside collection is better than via the HWRC. Whereas there is a maximum five-fold increase in energy consumption with recycling via the HWRC, there is only an approximately 9 % increase for collection via the kerbside, when compared to the base-case scenario (~two-fold increase when compared to zero recycling).
- Conversely, there is an approximately 84 % decrease in energy consumption compared to the base-case scenario if the maximum amount of material (garden waste plus kitchen compostable) is home composted rather than collected for central composting (garden waste only). If compared to zero recycling, the decrease in energy at maximum recycling is ~ 71 %.

- Incineration of the residual waste stream has a lower energy "footprint" than recycling of the garden waste combined with landfill of the residual waste. In addition, if recycling of garden waste is combined with incineration, the energy consumption will still be greater than with incineration alone. Hence, in this case, the best waste management option (in terms of the energy footprint) would be incineration of the residual waste stream, with no recycling of the garden waste (note: this is for the case where the transport, etc., energy savings through replacing use of peat-based compost with locally produced garden waste compost are not taken into account).

4.6 GLOBAL WASTE MANAGEMENT

- Generally, recycling via bring-sites consumes less energy (per tonne material transferred) than recycling via the HWRC, due to the lower transfer distance for recycling via bring-sites.
- In terms of annual energy consumption for global waste management, recycling via the dry recyclables kerbside scheme gives a lower energy consumption than recycling via the standard methods (banks plus PaperChain scheme). Maximum recycling via the dry recyclables scheme results in savings of 14.9 % compared to the base-case scenario, whilst they are only 11.4 % for maximum recycling via the standard methods.
- Incineration of the residual waste stream without recycling has a lower energy footprint than recycling of the five main waste fractions (glass, paper/card, plastics, metal cans, garden waste) and landfill of the residual waste. Energy savings of 30 % are achieved with a 100 % level of incineration, when compared to the base-case scenario. Conversely, with maximum recycling only, the savings are only 9.6 %.
- Combining base-case levels of recycling with incineration gives a lower energy consumption than incineration alone for levels of incineration up to ~ 70 %. Above this level the energy consumption is greater than for incineration alone. If, however, maximum recycling is combined with incineration, then the energy consumption for this scenario is lower (at all levels of incineration) than incineration alone.
- Recycling of the plastics fraction gives the lowest E-Factor (greatest relative energy savings compared to the base-case scenario) of 0.55, whilst recycling of garden waste gives the greatest E-Factor (5.11). In terms of absolute energy savings, however, recycling of metal cans (E-Factor = 0.74) gives the greatest energy savings (more than 60,000 GJ/year); whilst glass recycling gives the least savings (4000 GJ/year). In contrast, garden waste recycling gives an increase in energy consumption of ~ 133,000 GJ/year.
- Overall, maximum recycling of all five main waste fractions gives savings of more than 95,000 GJ/year, enough to provide electricity to provide electricity for more than 2400 households. Scaled up to a national basis, this is equivalent to approximately 637,000 households; or a population of ~ 1.5 million people – more than the entire population of the county of Hampshire.

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6 REFERENCES

1. Southampton City Council website, *'Southampton City Performance Plan 2004-05'* http://www.southampton.gov.uk/council/cityplans/cityperformanceplan/default.asp, web address last accessed November 2004
2. M.E.L Research Ltd., 1999, *Project Integra – Kerbside and Household Waste Recycling Centre: Waste Analysis and Questionnaire Survey Results*, M.E.L Research Ltd, Birmingham
3. K. Attrill, Waste Policy Assistant, Southampton City Council, 2003, *Personal Communication*
4. R. New, October 1994, *Analysis of Two Samples of Household (Dustbin) Waste for Hampshire County Council*, Report no. AEA/CS/18350083/032, AEA Technology
5. K. , Principal Research and Information Officer, Southampton City Council, February 2003, *Personal Communication*
6. D.W. Edwards, J. Schelling, 1999, *Municipal Waste Life Cycle Assessment; Part 2: Transport Analysis and Glass Case Study*, Trans IChemE, vol. 77, Part B
7. A. Richardson, Waste Policy Manager, Southampton City Council, 2003, *Personal Communication*
8. National Statistics website, Census 2001 population data, web address last accessed November 2003 http://www.statistics.gov.uk/census2001/pop2001/Southampton_UA.asp
9. Southampton City Council website, 'Contaminated Land: An Inspection Strategy for Southampton', Chapter 2, web address last accessed November 2004 http://www.southampton.gov.uk/environment/environmentalhealth/pollution/contaminated-land.asp
10. Commission of the European Communities, 1993, *CORINAIR Working Group on Emissions Factors for Calculating 1990 Emissions from Road Traffic, 1*, Office for Official Publications, Luxembourg
11. A. Lee, Project and Development Manager, Waste Management Section, Hampshire County Council, 2003, *Personal Communication*
12. J. Hunt, Waste Management Team, Environment Department, Hampshire County Council, April 2003, *Personal Communication*
13. T. Gent, Midland Glass Ltd, 2003, *Personal Communication*
14. Digest of United Kingdom Energy Statistics 2002, www.dti.gov.uk, 2003
15. F.R. McDougall, P. White, M. Franke, P. Hindle, 2001, *Integrated Solid Waste Management: A Life Cycle Inventory*, 2nd Edition, Blackwell Science, Oxford
16. Enviros, 2002, *Recycled Glass Market Study & Standards Review*, WRAP, Banbury
17. Associated British Ports website (http://www.abports.co.uk), 2003, *News Release 21st March 2003.*
18. T. Gent, Midland Glass Ltd, June 2003, *Personal Communication*
19. Captain G. Hindmarch, Marine Superintendent, Stephenson Clarke Shipping Ltd., June 2003, *Personal Communication*
20. BUWAL 250/II, 1998, *Life Cycle Inventories for Packagings, vol. II*, Swiss Agency for the Environment, Forests and Lansdscape (SAEFL), Berne, Switzerland
21. ETSU, 2000, *Energy Efficient Environmental Control in the Glass Industry (revised)*, Good Practice Guide 127, ETSU, Didcot
22. ETSU, 1997, *The Glass Container Industry (2nd Edition)*, Energy Consumption Guide 27, ETSU, Didcot
23. T. Cherrett, Transport Research Group, School of Civil Engineering & the Environment, University of Southampton, September 2003, *Personal Communication*

24. P. Sullivan, Transport Strategy Assistant, Southampton City Council, March 2003, *Personal Communication*.
25. Environmental Resource Management, January 2002*, Integrated Pollution Prevention and Control Application Document for Integra South West Energy Recovery Facility, at Marchwood Industrial Park, Marchwood*, prepared for Onyx Hampshire Ltd.
26. M. Nichol, Hampshire Waste Services, July 2003, *Personal Communication*
27. K. Riley, Managing Director, Onyx, Greater London and South, October 2003, *Personal Communication*
28. R. Feyerabend, Waste Policy Assistant, Southampton City Council, August 2003, *Personal Communication*
29. J. Collis, Project Director, Hampshire Waste Services Ltd, October 2003, *Personal Communication*
30. Southampton City View magazine, Issue 23, February/March 2004
31. M. Thomas, Operations Manager, Onyx Hampshire Ltd., November 2003, *Personal Communication*
32. F.R. McDougall, P. White, M. Franke, P. Hindle, 2001, *Integrated Solid Waste Management: A Life Cycle Inventory*, 2nd Edition, Blackwell Science, Oxford, pp438 – 440.
33. F.R. McDougall, P. White, M. Franke, P. Hindle, 2001, *Integrated Solid Waste Management: A Life Cycle Inventory*, 2nd Edition, Blackwell Science, Oxford, p446.
34. F.R. McDougall, P. White, M. Franke, P. Hindle, 2001, *Integrated Solid Waste Management: A Life Cycle Inventory*, 2nd Edition, Blackwell Science, Oxford, p450.
35. BUWAL 250/II, 1998, *Life Cycle Inventories for Packagings, vol. I*, Swiss Agency for the Environment, Forests and Lansdscape (SAEFL), Berne, Switzerland, p154
36. BUWAL 250/II, 1998, *Life Cycle Inventories for Packagings, vol. I*, Swiss Agency for the Environment, Forests and Lansdscape (SAEFL), Berne, Switzerland, p145
37. F.R. McDougall, P. White, M. Franke, P. Hindle, 2001, *Integrated Solid Waste Management: A Life Cycle Inventory*, 2nd Edition, Blackwell Science, Oxford, p440-446.
38. K. Riley, Managing Director, Onyx, Greater London and South, July 2004, *Personal Communication*
39. ORCA, *Information on Composting and Anaerobic Digestion*, ORCA Technical Publication No. 2, Organic Reclamation and Composting Association, Brussels, p.74
40. P. Mills, Onyx Hampshire Ltd., October 2003, *Personal Communication*
41. Greenfinch Limited, *Biogas Plant – Mass & Energy Balance*, http://www.greefinch.co.uk/mass.html, accessed June 2004
42. WRAP, 2002, *Kerbside Collection of Glass: A Brief Study into the Coverage and Effectiveness of Kerbside Collection in the UK*, WRAP, Banbury

APPENDICES

APPENDIX A: SUPPLEMENTARY NOTES TO THE VISUAL BASIC CODE

Glass Module

The analysis of glass has been completed using the excel file *Glass.xls* and the Module1 of the associated VB programme (use Alt F11 to access VB from Excel). There are 11 sub-programmes in this module, as detailed in the Table below. The names of the sub-programmes are also, to large extent, self-explanatory, and the main function and the level of importance (i.e. whether used only for analysis of glass, or widely re-used elsewhere as well) is also defined in the Table below (i.e. as local/global)

Name of Sub-programme	Main Purpose	Level of Use
Consumer_Transport	Calculates E (Energy) consumption for stage 1 transport	L
CulletTransferr	Calculates E consumption for CulletTransfer	L
GlassForUsers	Calculates how much glass in a scenario goes to various alternative uses (e.g. furnace, aggregates)	L
GlassFurnace	Calculates E consumption for glass manufacture	L
GlassKerbSideCollection	Calculates E consumption associated with kerbside collection	G
GlassProcessingPlant	Calculates E consumption for the Processing plant	L
InputWasteComposition	Inputs data from an Excel worksheet and makes further preliminary calculations	L *
Landfill	Calculates E consumption for transportation to landfill	G
LocalTransport	Calculates E consumption for stage 2 transport	G
Main	Calls the other relevant subs and sums up E consumption for separate stages to calculate overall values	L
OutputAggregateSensitivity	Calls Main in a cycle of variable end usage as aggregates, and outputs results in an Excel worksheet	L
OutputPlantDistanceSensitivity	Calls Main in a cycle of variable distances to processing plant, and outputs results in an Excel worksheet	L
OutputResponseCurves	Used to provide further output to Excel worksheet	L
OutputResponseSurface	Used in providing output in an Excel worksheet	L
RefuseCollection	Calculates E consumption for a RCV	G
RunningMainProgramme	Runs the Main programme (i.e. for glass) in a cycle	L
VehicleFC	Calculates vehicle's fuel consumption	G

G=Global, L=Local

The relevant Excel file (Glass.xls) contains the following worksheets:

- Inc – contains input data for the incineration matrix (trial only; updated code is used in more advanced versions of the model and is moved to another Module)
- InputWasteComposition – contains input data for material quantity (NB note that recycled values for all the materials other than glass have been set to zero, as this version of the module is only concerned with the analysis of the glass waste stream)
- Output – contains the output related to total E consumption in relation to variable recycling rate and kerbside coverage
- OutputPerKg - contains results of Total Energy Consumption per tonne of recovered material in relation to kerbside coverage and glass recycling rate
- StackChart - contains detailed output for the particular stages of the waste management process in relation to specified scenarios
- StackChart2 - may be used for detailed output together with the OutputResponseCurves sub-programme
- DistanceSens – contains results of sensitivity analysis on the distance to the Processing Plant
- AgregSens – contains results of sensitivity analysis on the amount of cullet diverted to use as aggregates

Dry Recyclables

Extensions of the model incorporating analysis of dry recyclables (i.e. paper, plastics and metals) are represented in the file *DryKerbAndOrg.xls* and the VB modules outlined below. An important part of this expanded model is the Waste Input Module (i.e. Module3), which is used to read the arrays of input data from the worksheet MainInputs, as well as for some preliminary calculations (e.g. assigning variables values for scenarios specified by an operator). There are only 2 sub-programmes in this module. Most operations are performed within the sub-programme called InputWasteComposition, which also uses a supplementary sub-programme called InputWasteMatrix to input specific array of data from the worksheet MainInputs.
It should be noted, that following the recommendation of the steering group, many of the waste properties (i.e. names, quantities, moisture contents, recycling rates, etc.) are represented as matrices. For the base-case scenario these matrices are kept in the worksheet MainInputs, while for other scenarios the matrices are recalculated in accordance with the conditions specified (e.g. recycling rates, split between various management and disposal options, etc.) both in the worksheet MainInputs and within the VB code. Care, therefore, should be taken whilst editing the input data, as a few unintentional changes may result in a considerable alteration of the output obtained. In addition, care should be taken while specifying such parameters as KerbsideParticipation and DryKerbCoverage, as the output will reflect the assumptions made. Please note that different modules may be fine-tuned in respect to those parameters in a different way, and care therefore should be taken whilst running simulations and interpreting the output.

In addition to the MainInputs worksheet, the relevant Excel file (*DryKerbAndOrg*.xls) contains the following worksheets:

- IncInput - contains input data for the incineration matrix and also used for some output
- DryKerbOutput – used to run simulations for Paper and Plastic and to display some of the output
- Plastic - used to run simulations for Plastic and to display detailed output of various stages of Plastic waste management
- Me - used to run simulations for Metals and to display detailed output of various stages of Metals' waste management

Paper & Card Module

The analysis of paper and card (NB for the purpose of this section terms 'paper' and 'paper and card' will be used interchangeably) waste stream have been completed using the Module2 of the associated VB programme (use Alt F11 to access VB from Excel). The names of the sub-programmes are, to a large extent, self-explanatory, and the main function/purpose of the most important sub-programmes are defined in the Table below.

Name of Sub-programme	Main Purpose	Level of Use
Incineration	Reads input information from worksheet IncInput and calculates E recovery from Incineration	G
MRFpaper	Calculates E consumption due to paper sorting at the MRF	L
PaperMain	Calls the other relevant subs and sums up E consumption for separate stages to calculate overall	L

	values	
PaperMill	Calculates E consumption at the paper mill	L
PaperTransfer	Calculates E consumption due to paper transfer	L
PrintEconsumption	Outputs the results of the scenario simulation into the Immediate Window and file PaperOutput.txt	L
SensitivityPaper	Calls sub-programme OutputDryKerb with input parameters for paper and card	L, makes use of the ServiceModule

G=Global, L=Local

In addition to the sub-programmes outlined above, the Paper/Card module also makes an extensive use of a number of sub-programmes from Module1 (i.e. a simplified Glass Module). These (e.g. Consumer_Transport, LocalTransport, VehicleFC) are detailed above (see Glass module), and are called with parameters for paper and card.

Plastic

The important sub-programmes in this module are detailed in the table below.

Name of Sub-programme	Main Purpose	Level of Use
MRFplastic	Calculates E consumption due to handling plastics at the MRF	L
PlasticMain	Calls the other relevant subs and sums up E consumption for separate stages to calculate overall values	L
MRFplasticSort	Calculates E consumption due to handling plastics at the specialised MRF	L
PlasticTransfer	Calculates E consumption due to plastic transfer	L
OuputPlasticDetailed	Outputs the detailed results of a scenario simulation into worksheet Plastic	L
PlasticManufacture	Calculates E consumption due to plastic manufacture	L
PlasticMassBalance	Calculates tonnages of plastic involved in different stages of the overall process	L
SensitivityPlastic	Calls sub-programme OutputDryKerb with input parameters for plastic	L, makes use of the ServiceModule

G=Global, L=Local

In addition to the sub-programmes outlined above, the Plastic module also makes an extensive use of a number of sub-programmes from Module1 (i.e. a simplified Glass Module). These (e.g. Consumer_Transport, LocalTransport, VehicleFC) are detailed above (see Glass module), and are called with parameters for the relevant plastic fractions (i.e. calculated in the plastic mass balance sub-programme).

Metals module

The most important subroutines for this module are given in the forthcoming Table. In addition to the sub-programmes outlined below, the Metals module also makes an extensive use of a number of sub-programmes from Module1 (i.e. a simplified Glass Module). These (e.g. Consumer_Transport, LocalTransport, VehicleFC) are detailed above (see Glass module), and are called with parameters relevant for metals.

Name of Sub-programme	Main Purpose	Level of Use
MRFMetal	Calculates E consumption due to handling metals at the MRF	L
MetalMain	Calls the other relevant subs and sums up E consumption for separate stages to calculate overall values	L
MRFMetalSort	Calculates E consumption due to handling plastics at the specialised MRF (or a scrap merchant)	L
MetalTransfer	Calculates E consumption due to transfer of metals	L

OuputMetalDetailed	Outputs the detailed results of a scenario simulation into worksheet Me	L
MetalManufacture	Calculates E consumption due to manufacture of metals for Soton	L
MetalMassBalance	Calculates tonnages of metals involved in different stages of the overall process	L

L=Local

Organics Module

The latest addition to the VB code is the organics module (ModuleOrganics – see file *DryKerbAndOrg).* This module has the following sub-programmes:

Name of Sub-programme	Main Purpose	Level of Use
OrganicsMain	Calls the other relevant subs and sums up E consumption for separate stages to calculate overall values	L
OrganicsMassBalance	Calculates tonnages of the considered organic materials involved in different stages of the overall process	L
OrganicsTransfer	Calculates E consumption due to transfer of the organic wastes considered	L
OutputOrganicsDetailed	Outputs the detailed results of a scenario simulation into worksheet Organics	L

L=Local

Service Module

This module is intended for the global use, i.e. eventually it is meant to be the place where various subs (e.g. involved in formatting/output) used extensively by other modules will be kept. Therefore, the sub-programmes in this module are global (unless indicated otherwise), and are currently as follows:

Name of Sub-programme	Main Purpose
Changing_Chart_Legend	Changes the legend of the output chart in accordance with the parameters passed into it
OutputDryKerb	Calls main sub-programme for a specified material, and outputs the E consumption into a worksheet table, from which a 3 D chart is subsequently created
RestoreDryKerbCoverage	Restores the input matrix for scenario coverage of the dry recyclables collection scheme in the worksheet MainInputs to the default values
RestoreRecyclingRates	Restores the input matrix for recycling rates in the worksheet MainInputs to the default values
RestoreSeparateKerbCoverages	Restores the input matrix for scenario coverage of the kerbside collection schemes for separate materials (e.g. paper chain) in the worksheet MainInputs to the default values

Current limitations, and further possible developments of the VB model

As any model is, by definition, a simplification of reality, a number of processes have been left outside the scope of the analysis presented in this report. One considerable limitation of the model is that currently it only takes into account household wastes, whilst commercial and industrial wastes have been left outside the system boundary for logistical reasons. It is expected, however, that the patterns observed should hold for these types of wastes as well, as most of the processes accounted for by the present model are also applicable to the management of commercial and industrial wastes.

It is worth mentioning that although the model is now quite complex and allows some sophisticated calculations, currently it is not yet user-friendly, and scenario simulations, therefore, normally require thorough preparation of the input data both in the Excel worksheets and within the VB code; in addition, for specific scenarios the latter may need to be fine-tuned, which was a normal occurrence whilst running the analysis reported. In some places there is redundancy in the code, and many of the variables defined in the first instance as, for example, variant, may be more appropriately redefined as double or single. Future work will, therefore, address these deficiencies, and it is intended to concentrate on compiling a more parsimonious code, and building a user-friendly interface, which would allow a wider range of users to easily run simulations in an interactive mode. Until then, however, it is strongly recommended that any scenarios should only be run in conjunction with the model developers (i.e. P. Dacombe & V. Krivtsov). It should also be noted, that the authors maintain copyright for the code, and if any party wishes to reproduce or apply any part of the code, it must, therefore, seek the authors' prior explicit permission.

APPENDIX B: HOUSEHOLD WASTE IN SOUTHAMPTON

Table B1: Household Waste in Southampton (base-case scenario)

Sub-category	Amount of Household Waste [tonnes/yr]	[wt %]	Amount to Disposal [tonnes/yr]	Amount Recycled [tonnes/yr]	Recycling Rate [%]	Recovery Rate [%]
Paper & card	**23561.95**	**26.02**	**19296.23**	**4265.72**	**18.10**	**20.72**
Newspaper	6663.82	7.36	4476.12	2187.70	32.83	32.83
Magazine	5039.86	5.56	3385.30	1654.56	32.83	32.83
Recycled Paper (non-packaging)	3135.15	3.46	2896.31	238.83	7.62	7.62
Paper Packaging	1128.43	1.25	1128.43	0.00	0.00	0.00
Card Packaging	3533.67	3.90	3385.30	148.36	4.20	4.20
Cardboard	863.79	0.95	827.52	36.27	4.20	4.20
Card non-packaging	225.69	0.25	225.69	0.00	0.00	0.00
Liquid Cartons	188.07	0.21	188.07	0.00	0.00	-
non-recyclable Paper	2783.47	3.07	2783.47	0.00	0.00	-
Plastic Film	**6657.76**	**7.35**	**6657.76**	**0.00**	**0.00**	-
Refuse sacks & Carrier Bags	3610.99	3.99	3610.99	0.00	0.00	-
Film - packaging	2896.31	3.20	2896.31	0.00	0.00	-
Film - non-packaging	150.46	0.17	150.46	0.00	0.00	-
Dense Plastic	**4980.67**	**5.50**	**4927.50**	**53.17**	**1.07**	**4.36**
PET Clear Bottles	471.96	0.52	451.37	20.58	4.36	4.36
PET Coloured Bottles	78.66	0.09	75.23	3.43	4.36	4.36
HDPE Clear Bottles	196.65	0.22	188.07	8.58	4.36	4.36
HDPE Coloured Bottles	393.30	0.43	376.14	17.15	4.36	4.36
PVC Clear Bottles	78.66	0.09	75.23	3.43	4.36	4.36
PVC Coloured Bottles	0.00	0.00	0.00	0.00	0.00	-
Food Packaging	1617.42	1.79	1617.42	0.00	0.00	-
non-Food Packaging	300.92	0.33	300.92	0.00	0.00	-
Other	1843.11	2.04	1843.11	0.00	0.00	-
Textiles	**4538.35**	**5.01**	**4325.67**	**212.68**	**4.69**	**4.69**
Natural & Man Made Fibres Oxfam bank	979.08	1.08	933.20	45.88	4.69	4.69
Natural & Man Made Fibres S. Army bank	1842.74	2.03	1756.38	86.36	4.69	4.69
Natural & Man Made Fibres TRAID bank	1076.45	1.19	1026.00	50.45	4.69	4.69
Natural & Man Made Fibres HWRC Textile	640.08	0.71	610.08	30.00	4.69	4.69
Misc. Combustible	**5370.04**	**5.93**	**5228.41**	**141.63**	**2.64**	**11.85**
Unclassified	1166.05	1.29	1166.05	0.00	0.00	-
Disposable Nappies	3009.16	3.32	3009.16	0.00	0.00	-
Shoes	380.56	0.42	376.14	4.42	1.16	1.16
Wood	814.27	0.90	677.06	137.21	16.85	16.85
Misc. non-combustible	**1707.22**	**1.89**	**977.98**	**729.25**	**42.72**	**59.86**
Unclassified	488.99	0.54	488.99	0.00	0.00	0.00
Hardcore/rubble	195.78	0.22	78.58	117.19	59.86	59.86
Mixed Soil	989.48	1.09	397.17	592.31	59.86	59.86
Soil	32.98	0.04	13.24	19.74	59.86	59.86
Glass	**5325.62**	**5.88**	**3949.52**	**1376.10**	**25.84**	**26.21**

Clear Bottles & Jars	2895.84	3.20	2407.33	488.52	16.87	16.87
Green Bottles & Jars	1733.46	1.91	977.98	755.48	43.58	43.58
Brown Bottles & Jars	621.09	0.69	488.99	132.11	21.27	21.27
Other Glass	75.23	0.08	75.23	0.00	0.00	-
Ferrous metals	**3792.47**	**4.19**	**2745.86**	**1046.61**	**27.60**	**28.74**
Food Cans	1834.91	2.03	1805.50	29.42	1.60	1.60
Beverage Cans	38.23	0.04	37.61	0.61	1.60	1.60
Batteries	72.46	0.08	37.61	34.85	48.09	48.09
Aerosols	150.46	0.17	150.46	0.00	0.00	-
Other Ferrous	1509.81	1.67	714.68	795.14	52.66	52.66
White Goods	186.60	0.21	0.00	186.60	100.00	100.00
Non-ferrous metals	**876.33**	**0.97**	**827.52**	**48.81**	**5.57**	**7.50**
Aluminium Foil	225.69	0.25	225.69	0.00	0.00	-
Beverage Cans - Aluminium	191.14	0.21	188.07	3.06	1.60	1.60
Aluminium Food Cans	76.45	0.08	75.23	1.23	1.60	1.60
Other	383.05	0.42	338.53	44.52	11.62	11.62
Putrescibles	**24187.08**	**26.71**	**22643.92**	**1543.17**	**6.38**	**7.56**
Garden Waste	12865.12	14.21	11321.96	1543.17	11.99	11.99
Kitchen Compostable	7560.51	8.35	7560.51	0.00	0.00	0.00
Kitchen non-Compostable	3761.45	4.15	3761.45	0.00	0.00	-
Unclassified	0.00	0.00	0.00	0.00	0.00	-
Fines	**3234.85**	**3.57**	**3234.85**	**0.00**	**0.00**	**-**
Combustible Particles < 10mm	1617.42	1.79	1617.42	0.00	0.00	-
non-Comb. Particles < 10mm	1617.42	1.79	1617.42	0.00	0.00	-
Sub-total:	**84232.35**	**93.01**	**74815.20**	**9417.15**	**11.18**	**16.03**
Additional material not included above:						
HWRC General Waste (Amenity)	6158.48	6.80	6158.48	0.00	0.00	-
HWRC Bricabrac	120.58	0.13	0.00	120.58	100.00	100
HWRC Oil	15.58	0.02	0.00	15.58	100.00	100
HWRC Free Bay	36	0.04	0	36.00	100.00	100
Oxfam Book Banks	4.52	0.00	0.00	4.52	100.00	100
Oxfam printer cartridge/mobile phone banks	0.02	0.00	0.00	0.02	100.00	100
Sub-total	**6335.18**	**6.99**	**6158.48**	**176.7**	**2.79**	**100**
Overall Total:	**90567.53**	**100.00**	**80973.68**	**9593.85**	**10.59**	**16.30**

Table B2: Recycling Rates

	Bring-Sites		HWRC		Kerbside	
Sub-category	**[tonnes/yr]**	**[%]**	**[tonnes/yr]**	**[%]**	**[tonnes/yr]**	**[%]**
Paper & card	**776.93**	**3.30**	**294.79**	**1.25**	**3194.00**	**13.56**
Newspaper	323.27	4.85	45.84	0.69	1818.59	27.29
Magazine	244.49	4.85	34.67	0.69	1375.41	27.29
Recycled Paper (non-packaging)	209.17	6.67	29.66	0.95	0.00	0.00
Paper Packaging	0.00	0.00	0.00	0.00	0.00	0.00
Card Packaging	0.00	0.00	148.36	4.20	0.00	0.00
Cardboard	0.00	0.00	36.27	4.20	0.00	0.00
Card non-packaging	0.00	0.00	0.00	0.00	0.00	0.00
Liquid Cartons	0.00	0.00	0.00	0.00	0.00	0.00
non-recyclable Paper	0.00	0.00	0.00	0.00	0.00	0.00
Plastic Film	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Refuse sacks & Carrier Bags	0.00	0.00	0.00	0.00	0.00	0.00
Film - packaging	0.00	0.00	0.00	0.00	0.00	0.00
Film - non-packaging	0.00	0.00	0.00	0.00	0.00	0.00
Dense Plastic	**43.95**	**0.88**	**9.224**	**0.19**	**0.00**	**0.00**
PET Clear Bottles	17.01	3.60	3.57	0.76	0.00	0.00
PET Coloured Bottles	2.84	3.60	0.60	0.76	0.00	0.00
HDPE Clear Bottles	7.09	3.60	1.49	0.76	0.00	0.00
HDPE Coloured Bottles	14.18	3.60	2.98	0.76	0.00	0.00
PVC Clear Bottles	2.84	3.60	0.60	0.76	0.00	0.00
PVC Coloured Bottles	0.00	0.00	0.00	0.00	0.00	0.00
Food Packaging	0.00	0.00	0.00	0.00	0.00	0.00
non-Food Packaging	0.00	0.00	0.00	0.00	0.00	0.00
Other	0.00	0.00	0.00	0.00	0.00	0.00
Textiles	**182.69**	**4.03**	**30.00**	**0.66**	**0.00**	**0.00**
Natural & Man Made Fibres Oxfam bank	45.88	4.69	0.00	0.00	0.00	0.00
Natural & Man Made Fibres S. Army bank	86.36	4.69	0.00	0.00	0.00	0.00
Natural & Man Made Fibres TRAID bank	50.45	4.69	0.00	0.00	0.00	0.00
Natural & Man Made Fibres HWRC Textile	0.00	0.00	30.00	4.69	0.00	0.00
Misc. Combustible	**4.42**	**0.08**	**137.21**	**2.56**	**0.00**	**0.00**
Unclassified	0.00	0.00	0.00	0.00	0.00	0.00
Disposable Nappies	0.00	0.00	0.00	0.00	0.00	0.00
Shoes	4.42	1.16	0.00	0.00	0.00	0.00
Wood	0.00	0.00	137.21	16.85	0.00	0.00
Misc. non-combustible	**0.00**	**0.00**	**729.25**	**42.72**	**0.00**	**0.00**
Unclassified	0.00	0.00	0.00	0.00	0.00	0.00
Hardcore/rubble	0.00	0.00	117.19	59.86	0.00	0.00
Mixed Soil	0.00	0.00	592.31	59.86	0.00	0.00
Soil	0.00	0.00	19.74	59.86	0.00	0.00
Glass	**1271.00**	**23.87**	**105.10**	**1.97**	0.00	**0.00**
Clear Bottles & Jars	451.21	15.58	37.31	1.29	0.00	0.00
Green Bottles & Jars	697.78	40.25	57.70	3.33	0.00	0.00
Brown Bottles & Jars	122.02	19.65	10.09	1.62	0.0	0.00

Other Glass	0.00	0.00	0.00	0.00	0.0	0.00
Ferrous metals	**28.69**	**0.76**	**1017.92**	**26.84**	**0.00**	**0.00**
Food Cans	28.11	1.53	1.31	0.07	0.00	0.00
Beverage Cans	0.59	1.53	0.03	0.07	0.00	0.00
Batteries	0.00	0.00	34.85	48.09	0.00	0.00
Aerosols	0.00	0.00	0.00	0.00	0.00	0.00
Other Ferrous	0.00	0.00	795.14	52.66	0.00	0.00
White Goods	0.00	0.00	186.60	100.00	0.00	0.00
Non-ferrous metals	**4.10**	**0.47**	**44.71**	**5.10**	**0.00**	**0.00**
Aluminium Foil	0.00	0.00	0.00	0.00	0.00	0.00
Beverage Cans - Aluminium	2.93	1.53	0.14	0.07	0.00	0.00
Aluminium Food Cans	1.17	1.53	0.05	0.07	0.00	0.00
Other	0.00	0.00	44.52	11.62	0.00	0.00
Putrescibles	**0.00**	**0.00**	**1238.65**	**5.12**	**304.52**	**1.26**
Garden Waste	0.00	0.00	1238.65	9.63	304.52	2.37
Kitchen Compostable	0.00	0.00	0.00	0.00	0.00	0.00
Kitchen non-Compostable	0.00	0.00	0.00	0.00	0.00	0.00
Unclassified	0.00	0.00	0.00	0.00	0.00	0.00
Fines	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Combustible Particles < 10mm	0.00	0.00	0.00	0.00	0.00	0.00
non-Comb. Particles < 10mm	0.00	0.00	0.00	0.00	0.00	0.00
Sub-total	**2311.77**	**2.74**	**3606.86**	**4.28**	**3498.52**	**4.15**
Additional material not included above:						
HWRC General Waste (Amenity)	0.00	0.00	0.00	0.00	0.00	0.00
HWRC Bricabrac	0.00	0.00	120.58	100.00	0.00	0.00
HWRC Oil	0.00	0.00	15.58	100.00	0.00	0.00
HWRC Free Bay	0.00	0.00	36.00	100.00	0.00	0.00
Oxfam Book Banks	4.52	100.00	0.00	0.00	0.00	0.00
Oxfam printer cartridge/mobile phone banks	0.02	100.00	0.00	0.00	0.00	0.00
Sub-total	**4.54**	**0.07**	**172.16**	**2.72**	**0.00**	**0.00**
Overall Total:	**2316.31**	**2.56**	**3779.02**	**4.17**	**3498.52**	**3.86**

Table B3: Expanded Refuse Composition

Main Category	Sub-category	wt %	kg/hh/week
Paper & card	Newspaper	5.98	0.94
	Magazine	4.52	0.71
	Recycled Paper (non-packaging)	3.87	0.61
	Paper Packaging	1.51	0.24
	Card Packaging	4.52	0.71
	Cardboard	1.11	0.17
	Card non-packaging	0.30	0.05
	Liquid Cartons	0.25	0.04
	non-recyclable Paper	3.72	0.58
Plastic Film	Refuse sacks & Carrier Bags	4.83	0.76
	Film - packaging	3.87	0.61
	Film - non-packaging	0.20	0.03
Dense Plastic	PET Clear Bottles	0.60	0.09
	PET Coloured Bottles	0.10	0.02
	HDPE Clear Bottles	0.25	0.04
	HDPE Coloured Bottles	0.50	0.08
	PVC Clear Bottles	0.10	0.02
	PVC Coloured Bottles	0.00	0.00
	Food Packaging	2.16	0.34
	non-Food Packaging	0.40	0.06
	Other	2.46	0.39
Textiles	Natural & Man Made Fibres Oxfam bank	1.25	0.20
	Natural & Man Made Fibres Salvation Army bank	2.35	0.37
	Natural & Man Made Fibres TRAID bank	1.37	0.21
	Natural & Man Made Fibres HWRC Textile	0.82	0.13
Misc. Combustibles	Unclassified	1.56	0.24
	Disposable Nappies	4.02	0.63
	Shoes	0.50	0.08
	Wood	0.90	0.14
Misc. non-combustibles	Unclassified	0.65	0.10
	Hardcore/rubble	0.11	0.02
	Mixed Soil	0.53	0.08
	Soil	0.02	0.00
Glass	Clear Bottles & Jars	3.22	0.50
	Green Bottles & Jars	1.31	0.20
	Brown Bottles & Jars	0.65	0.10
	Other Glass	0.10	0.02
Ferrous Metals	Food Cans	2.41	0.38
	Beverage Cans	0.05	0.01
	Batteries	0.05	0.01
	Aerosols	0.20	0.03
	Other Ferrous	0.96	0.15
	White Goods	0.00	0.00
Non-ferrous metals	Aluminium Foil	0.30	0.05
	Beverage Cans - Aluminium	0.25	0.04
	Aluminium Food Cans	0.10	0.02
	Other	0.45	0.07
Putrescibles	Garden Waste	15.13	2.37

	Kitchen Compostable	10.11	1.58
	Kitchen non-Compostable	5.03	0.79
	Unclassified	0.00	0.00
Fines	Combustible Particles < 10mm	2.16	0.34
	non-Combustibles Particles < 10mm	2.16	0.34
Total:		**100**	**15.66**

Table B4: Expanded Refuse Composition (Properties)

Sub-category	Moisture content [wt %]	Net CV [MJ/kg]	Ash content [wt %]
Paper & card			
Newspaper	0.36	1.10	0.09
Magazine	0.21	0.77	0.12
Recycled Paper (non-packaging)	0.40	0.60	0.21
Paper Packaging	0.15	0.23	0.08
Card Packaging	0.24	0.74	0.23
Cardboard	0.06	0.18	0.06
Card non-packaging	0.02	0.05	0.02
Liquid Cartons	0.01	0.07	0.00
non-recyclable Paper	0.38	0.58	0.20
Plastic Film			
Refuse sacks & Carrier Bags	0.01	2.00	0.05
Film - packaging	0.01	1.61	0.04
Film - non-packaging	0.00	0.08	0.00
Dense Plastic			
PET Clear Bottles	0.00	0.13	0.00
PET Coloured Bottles	0.00	0.02	0.00
HDPE Clear Bottles	0.00	0.11	0.00
HDPE Coloured Bottles	0.00	0.22	0.00
PVC Clear Bottles	0.00	0.02	0.00
PVC Coloured Bottles	0.00	0.00	0.00
Food Packaging	0.00	0.82	0.01
non-Food Packaging	0.00	0.15	0.00
Other	0.00	0.99	0.02
Textiles			
Natural & Man Made Fibres Oxfam bank	0.09	0.20	0.03
Natural & Man Made Fibres S. Army bank	0.16	0.37	0.06
Natural & Man Made Fibres TRAID bank	0.09	0.22	0.04
Natural & Man Made Fibres HWRC Textile	0.06	0.13	0.02
Misc. Combustible			
Unclassified	0.02	0.40	0.15
Disposable Nappies	3.42	0.08	0.06
Shoes	0.04	0.08	0.11
Wood	0.18	0.18	0.01
Misc. non-combustible			
Unclassified	0.00	0.00	0.65
Hardcore/rubble	0.00	0.00	0.11
Mixed Soil	0.13	0.00	0.50
Soil	0.01	0.00	0.02
Glass			
Clear Bottles & Jars	0.00	0.01	3.20
Green Bottles & Jars	0.00	0.00	1.30
Brown Bottles & Jars	0.00	0.00	0.65
Other Glass	0.00	0.00	0.10
Ferrous metals			
Food Cans	0.00	0.02	0.00
Beverage Cans	0.00	0.00	0.05

Batteries	0.00	0.00	0.05
Aerosols	0.00	0.00	0.20
Other Ferrous	0.00	0.00	0.96
White Goods	0.00	0.00	0.00
Non-ferrous metals			
Aluminium Foil	0.00	0.00	0.30
Beverage Cans - Aluminium	0.00	0.00	0.25
Aluminium Food Cans	0.00	0.00	0.00
Other	0.00	0.00	0.45
Putrescibles			
Garden Waste	1.51	2.76	0.58
Kitchen Compostable	7.91	0.22	0.11
Kitchen non-Compostable	1.95	0.84	0.16
Unclassified	0.00	0.00	0.00
Fines			
Combustible Particles < 10mm	0.12	0.32	0.66
non-Combustibles Particles < 10mm	0.00	0.00	2.16
Total:	**17.53**	**16.31**	**14.05**

Table B5: Refuse Composition Sub-Category Component Properties

Sub-category	Moisture content [wt %]	Gross CV [MJ/kg]	Ash content [wt %]
Paper & card			
Newspaper	5.97	18.55	1.43
Magazine	4.71	17.07	2.64
Recycled Paper (non-packaging)	10.24	15.75	5.38
Paper Packaging	10.24	15.75	5.38
Card Packaging	5.20	16.38	5.06
Cardboard	5.20	16.38	5.06
Card non-packaging	5.20	16.38	5.06
Liquid Cartons	3.45	26.35	1.17
non-recyclable Paper	10.24	15.75	5.38
Plastic Film			
Refuse sacks & Carrier Bags	0.20	41.5	1.00
Film - packaging	0.20	41.5	1.00
Film - non-packaging	0.20	41.5	1.00
Dense Plastic			
PET Clear Bottles	0.20	22.00	0.00
PET Coloured Bottles	0.20	22.00	0.00
HDPE Clear Bottles	0.16	43.10	0.16
HDPE Coloured Bottles	0.16	43.10	0.16
PVC Clear Bottles	0.20	22.59	2.06
PVC Coloured Bottles	0.20	22.59	2.06
Food Packaging	0.20	38	0.45
non-Food Packaging	0.20	38	0.45
Other	0.20	40.32	1.00
Textiles			
Natural & Man Made Fibres Oxfam bank	6.90	16.12	2.62
Natural & Man Made Fibres S. Army bank	6.90	16.12	2.62
Natural & Man Made Fibres TRAID bank	6.90	16.12	2.62
Natural & Man Made Fibres HWRC Textile	6.90	16.12	2.62
Misc. Combustible			
Unclassified	1.20	25.93	9.88
Disposable Nappies	85.00	4.00	1.50
Shoes	7.46	16.77	21.16
Wood	20.00	20.14	0.80
Misc. non-combustible			
Unclassified	0.00	0.00	100.00
Hardcore/rubble	0.00	0.00	100.00
Mixed Soil	25.00	1.00	95.00
Soil	35.00	2.00	90.00
Glass			
Clear Bottles & Jars	0.00	0.20	99.41
Green Bottles & Jars	0.00	0.20	99.41
Brown Bottles & Jars	0.00	0.20	99.41
Other Glass	0.00	0.00	100.00
Ferrous metals			
Food Cans	0.00	0.74	100.00

Beverage Cans	0.00	0.00	100.00
Batteries	0.00	0.00	100.00
Aerosols	0.00	0.00	100.00
Other Ferrous	0.00	0.00	100.00
White Goods	0.00	0.00	100.00
Non-ferrous metals			
Aluminium Foil	0.00	0.00	100.00
Beverage Cans - Aluminium	0.00	0.00	100.00
Aluminium Food Cans	0.00	0.74	100.00
Other	0.00	0.00	100.00
Putrescibles			
Garden Waste	9.97	18.49	3.82
Kitchen Compostable	78.29	4.17	1.06
Kitchen non-Compostable	38.74	17.73	3.11
Unclassified	38.74	17.73	0.00
Fines			
Combustible Particles < 10mm	5.47	14.79	30.34
non-Combustibles Particles < 10mm	0.00	0.00	100.00

Table B6: Breakdown of Material taken to HWRC

Collection Facility	Tonnes/year taken to HWRC	Fraction of total material taken to HWRC [%]	Mass taken to HWRC [kg/trip]	Energy Consumption [GJ/year]
Glass bank	105.10	2.91	0.58	170.32
Paper bank	110.16	3.05	0.61	178.52
Card bank	184.63	5.12	1.02	299.20
Plastics bank	9.22	0.26	0.05	14.94
Mixed metals can bank	1.53	0.04	0.01	2.48
Metals skip:				
ferrous	795.14	22.05	4.41	1288.54
non-ferrous	44.52	1.23	0.25	72.15
White goods	186.60	5.17	1.03	302.39
Batteries	34.85	0.97	0.19	56.48
Garden waste skip	1238.65	34.34	6.87	2007.26
Wood	137.21	3.80	0.76	222.35
Textiles	30.00	0.83	0.17	48.62
Rubble skip	729.25	20.22	4.04	1181.77
Totals:	**3606.86**	**100.00**	**20.00**	**5844.99**

Table B7: Energy Consumption Associated with Refuse Collection and Landfill Transfer

Sub-category	[wt %]	Energy Consumption [GJ/year] Refuse collection	Landfill transfer
Paper & card	**25.79**	**923.42**	**817.18**
Newspaper	5.98	214.20	189.56
Magazine	4.52	162.00	143.37
Recycled Paper (non-packaging)	3.87	138.60	122.66
Paper Packaging	1.51	54.00	47.79
Card Packaging	4.52	162.00	143.37
Cardboard	1.11	39.60	35.04
Card non-packaging	0.30	10.80	9.56
Liquid Cartons	0.25	9.00	7.96
non-recyclable Paper	3.72	133.20	117.88
Plastic Film	**8.90**	**318.61**	**281.95**
Refuse sacks & Carrier Bags	4.83	172.80	152.92
Film - packaging	3.87	138.60	122.66
Film - non-packaging	0.20	7.20	6.37
Dense Plastic	**6.59**	**235.81**	**208.68**
PET Clear Bottles	0.60	21.60	19.12
PET Coloured Bottles	0.10	3.60	3.19
HDPE Clear Bottles	0.25	9.00	7.96
HDPE Coloured Bottles	0.50	18.00	15.93
PVC Clear Bottles	0.10	3.60	3.19
PVC Coloured Bottles	0.00	0.00	0.00
Food Packaging	2.16	77.40	68.50
non-Food Packaging	0.40	14.40	12.74
Other	2.46	88.20	78.05
Textiles	**5.78**	**207.00**	**183.19**
Natural & Man Made Fibres Oxfam bank	1.25	44.66	39.52
Natural & Man Made Fibres S. Army bank	2.35	84.05	74.38
Natural & Man Made Fibres TRAID bank	1.37	49.10	43.45
Natural & Man Made Fibres HWRC Textile	0.82	29.20	25.84
Misc. Combustible	**6.99**	**250.21**	**221.42**
Unclassified	1.56	55.80	49.38
Disposable Nappies	4.02	144.00	127.44
Shoes	0.50	18.00	15.93
Wood	0.90	32.40	28.67
Misc. non-combustible	**1.31**	**46.80**	**41.42**
Unclassified	0.65	23.40	20.71
Hardcore/rubble	0.11	3.76	3.33
Mixed Soil	0.53	19.01	16.82
Soil	0.02	0.63	0.56
Glass	**5.28**	**189.00**	**167.26**
Clear Bottles & Jars	3.22	115.20	101.95
Green Bottles & Jars	1.31	46.80	41.42
Brown Bottles & Jars	0.65	23.40	20.71
Other Glass	0.10	3.60	3.19

Ferrous metals	**3.67**	**131.40**	**116.29**
Food Cans	2.41	86.40	76.46
Beverage Cans	0.05	1.80	1.59
Batteries	0.05	1.80	1.59
Aerosols	0.20	7.20	6.37
Other Ferrous	0.96	34.20	30.27
White Goods	0.00	0.00	0.00
Non-ferrous metals	**1.11**	**39.60**	**35.04**
Aluminium Foil	0.30	10.80	9.56
Beverage Cans - Aluminium	0.25	9.00	7.96
Aluminium Food Cans	0.10	3.60	3.19
Other	0.45	16.20	14.34
Putrescibles	**30.27**	**1083.62**	**958.95**
Garden Waste	15.13	541.81	479.48
Kitchen Compostable	10.11	361.81	320.18
Kitchen non-Compostable	5.03	180.00	159.29
Unclassified	0.00	0.00	0.00
Fines	**4.32**	**154.80**	**136.99**
Combustible Particles < 10mm	2.16	77.40	68.50
non-Combustibles Particles < 10mm	2.16	77.40	68.50
Total:	**100.00**	**3580.28**	**3168.37**

APPENDIX C: MATERIALS RECOVERY FACILITY MASS/ENERGY BALANCE

Material	destination	tonnes	tonnes per load	number of loads	miles to market	total miles to market
newspapers & magazines (a)	Shotton	24200	20	1210	225	272250
newspapers & magazines (b)	Aylesford	3800	20	190	93	17670
mixed paper	Taplow	18592	14	1328	60	79680
plastics	St Helens	840	18	47	229	10687
ferrous	Llanelli	1232	20	62	185	11396
aluminium	Warrington	56	8	7	223	1561
fibre residue	Slough	2800	12	233	60	14000
residue disposal	Blue Haze	4480	10	448	59	26432
Total:		**56000**		**3525**		**433,676**

Table C1: Materials Recovery Facility Materials Balance

Table C2: Materials Recovery Facility Annual Energy Usage

Electrical usage:	**no. of units [kWh]**
day:	661881
night:	177050
total:	838931
Mobile plant fuel usage:	**amount [litres]**
Red diesel	7160

Material:	tonnes	Composition [wt%]	total losses [%]	losses to fiber residue [%]	losses to residue disposal [%]
newspapers & magazines (a)	27879.6	49.79	13.20	5.22	7.98
newspapers & magazines (b)	4377.8	7.82	13.20	5.22	7.98
Mixed paper	21418.9	38.25	13.20	5.22	7.98
Plastics	917.2	1.64	8.42	0.00	8.42
Ferrous	1345.3	2.40	8.42	0.00	8.42
Aluminium	61.1	0.11	8.42	0.00	8.42
fibre residue	0.0	0.00	0.00	0.00	-
[1] other misc. (misc. contaminants)	0.0	0.00	0.00	0.00	-
TOTAL:	**56000.0**	**100.00**			

[1] other misc. (misc. contaminants) is assumed to be 'residue disposal' material given in Table C1.

Table C3: Estimated Materials Input to Materials Recovery Facility

APPENDIX D: CALCULATION OF MASS OF PLASTICS TAKEN TO BRING-SITE PER TRIP

Estimation of Mass of Plastics taken to Bring-Sites per Car Trip:

• mass of 4 x 4 litre milk containers from supermarket:	~ 170 grams
• mass of 1 x 4 litre milk containers from supermarket:	~ 42.5 grams
• a carrier bag can hold approximately:	6 containers *
• mass of plastics per carrier bag:	~ 255 grams
• assume that average car load per trip is:	3 carrier bags
• therefore average mass of plastics per car trip:	765 grams
• hence, use an estimate of:	750 grams per trip

* partially crushed containers (i.e. crushed by householder)

APPENDIX E: ENERGY CONSUMPTION COMPARISON DATA

	Glass		Paper		Plastics		Metal Cans		Garden Waste
	bring-site	HWRC	bring-site	HWRC	bring-site	HWRC	bring-site	HWRC	HWRC
number of sites	86	1	22	1	5	1	5	1	1
stage 1 transport									
tonnes transferred	1271.00	105.10	776.93	110.16	43.95	9.22	32.79	1.53	1238.65
tonnes per site	14.78	105.10	35.32	110.16	8.79	9.22	6.56	1.53	1238.65
%age of trips spec. for recycling	27.80	100	35.45	100	37.65	100	37.65	100	100
transfer distance (return-journey)	0.267	5	0.528	5	1.11	5	1.11	5	5
load per trip [kg]	4.5	0.58	4.5	0.61	0.75	0.05	4.5	0.01	6.87
percentage of load	100	2.91	100	3.05	100	0.26	100	0.04	34.34
number of trips	78523	180343	61203	180343	22063	180343	2743	180414	180343
transfer-miles	20954	26275	32292	27540	24418	2306	3036	383	309663
transfer-miles/tonne	16.49	250.00	41.56	250.00	555.59	250.00	92.60	250.00	250.00
Energy Consumption [GJ/yr]	135.83	170.32	209.32	178.52	158.28	14.95	19.68	2.48	2007.26
Energy Consumption [GJ/tonne]	0.107	1.621	0.269	1.621	3.601	1.621	0.600	1.621	1.621
stage 2 transport									
transfer distance (return-journey)	7.34	5.52	17.14	19.20	17.14	19.20	49.08	38.00	26.60
number of collections	348	35	105.00	13.00	169.00	29	69.00	12.00	231
Tonnes transferred/collection									
transfer-miles	2554	196	1800	250	2897	562	3387	456	6145
transfer-miles/tonne	2.01	1.86	2.32	2.27	65.91	60.97	103.28	298.04	4.96
Energy Consumption [GJ/yr]	92.97	7.82	54.38	7.42	87.53	16.72	92.13	12.62	175.56
Energy Consumption [GJ/tonne]	0.073	0.074	0.070	0.067	1.992	1.812	2.810	8.252	0.142
Total									
transfer-miles	23509	26471	34092	27790	27315	2868	6423	839	315807
transfer-miles/tonne	18.50	251.86	43.88	252.27	621.50	310.97	195.88	548.04	254.96
Energy Consumption [GJ/yr]	228.80	178.14	263.70	185.94	245.81	31.66	111.81	15.10	2182.82
Energy Consumption [GJ/tonne]	0.180	1.695	0.339	1.688	5.593	3.433	3.410	9.872	1.762

Table E1: Comparison of Recycling via Bring-Sites and via HWRC

	Glass		Paper & card		Plastics		Metals		Organics		TOTAL	
	base-case	max. recovery	base-case	max. recovery	base-case	max. recovery	base-case	max. recovery	base-case	max. recovery	base-case	max. recovery
GJ/year total	**60454**	**56455**	**640943**	**608064**	**39609**	**21595**	**229710**	**169614**	**4831**	**24694**	**975547**	**880422**
GJ/year processing/manufacture	59077	52551	635723	598420	38237	13231	226695	157406	118	1077	959850	822685
GJ/year recycling related components	1021	3896	3479	8604	327	7422	2693	12076	2609	22512	10130	54510
GJ/year refuse collection/landfill transfer	356	7	1741	1041	1045	941	322	133	2104	1105	5568	3227
base-case material recovery rate	26.21	100.00	32.83	100.00	4.36	100.00	1.60	100.00	11.99	99.78	20.60	99.92
waste fraction recycling rate	25.84	98.59	18.10	51.47	0.46	10.48	23.46	68.58	6.72	52.01	12.07	49.58
tonnes recycled at base-case recovery rate	1376.1	5250.39	4265.72	12127.15	53.17	1219.22	34.32	2140.73	1543.17	12837.01	7272.48	33574.50
savings/increases due to recycling:												
GJ/tonne recycled total savings	**1.03**		**4.18**		**15.45**		**28.53**		**-1.76**		**3.62**	
GJ/tonne recycled process/manufacturing savings	1.68		4.75		21.45		32.89		-0.08		5.21	
GJ/tonne recycled recycling related increases	-0.74		-0.65		-6.08		-4.45		-1.76		-1.69	
GJ/tonne recycled refuse collection/landfill transfer savings	0.09		0.09		0.09		0.09		0.09		0.09	

Table E2: Comparison of Energy Consumption for Base-Case Scenario and Maximum Recovery

Table E3: Effect of Recycling on Refuse Composition (expanded)

Waste sub-category	Base-Case scenario	glass	paper/ card	plastics	metals	garden waste	ALL	Dry Recyclables only
	[wt %]	[wt %]	[wt %]	[wt %]	[wt %]	[wt %]	[wt %]	[wt %]
Newspaper	5.98	6.31	0.00	6.08	6.16	7.05	0.00	0.00
Magazine	4.52	4.77	0.00	4.60	4.66	5.33	0.00	0.00
Recycled Paper (non-packaging)	3.87	4.08	4.33	3.93	3.98	4.56	5.97	0.00
Paper Packaging	1.51	1.59	1.69	1.53	1.55	1.78	2.33	0.00
Card Packaging	4.52	4.77	5.06	4.60	4.66	5.33	6.98	0.00
Cardboard	1.11	1.17	1.24	1.12	1.14	1.30	1.71	0.00
Card non-packaging	0.30	0.32	0.34	0.31	0.31	0.36	0.47	0.00
Liquid Cartons	0.25	0.27	0.28	0.26	0.26	0.30	0.39	0.34
non-recyclable Paper	3.72	3.92	4.16	3.78	3.83	4.38	5.74	5.04
Refuse sacks & Carrier Bags	4.83	5.09	5.39	4.90	4.97	5.69	7.45	6.54
Film - packaging	3.87	4.08	4.33	3.93	3.98	4.56	5.97	5.25
Film - non-packaging	0.20	0.21	0.22	0.20	0.21	0.24	0.31	0.27
PET Clear Bottles	0.60	0.64	0.67	0.00	0.62	0.71	0.00	0.00
PET Coloured Bottles	0.10	0.11	0.11	0.00	0.10	0.12	0.00	0.00
HDPE Clear Bottles	0.25	0.27	0.28	0.00	0.26	0.30	0.00	0.00
HDPE Coloured Bottles	0.50	0.53	0.56	0.00	0.52	0.59	0.00	0.00
PVC Clear Bottles	0.10	0.11	0.11	0.00	0.10	0.12	0.00	0.00
PVC Coloured Bottles	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Food Packaging	2.16	2.28	2.42	2.20	2.22	2.55	3.34	2.93
non-Food Packaging	0.40	0.42	0.45	0.41	0.41	0.47	0.62	0.54
Other	2.46	2.60	2.75	2.50	2.53	2.90	3.80	3.34
Natural & Man Made Fibres Oxfam bank	1.25	1.32	1.39	1.27	1.28	1.47	1.92	1.69
Natural & Man Made Fibres S. Army bank	2.35	2.48	2.62	2.38	2.42	2.77	3.62	3.18
Natural & Man Made Fibres TRAID bank	1.37	1.45	1.53	1.39	1.41	1.62	2.12	1.86
Natural & Man Made Fibres HWRC Textile	0.82	0.86	0.91	0.83	0.84	0.96	1.26	1.10
Unclassified	1.56	1.64	1.74	1.58	1.60	1.84	2.40	2.11
Disposable Nappies	4.02	4.24	4.49	4.09	4.14	4.74	6.21	5.45
Shoes	0.50	0.53	0.56	0.51	0.52	0.59	0.78	0.68

Wood	0.90	0.95	1.01	0.92	0.93	1.07	1.40	1.23
Unclassified	0.65	0.69	0.73	0.66	0.67	0.77	1.01	0.89
Hardcore/rubble	0.11	0.11	0.12	0.11	0.11	0.12	0.16	0.14
Mixed Soil	0.53	0.56	0.59	0.54	0.55	0.63	0.82	0.72
Soil	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02
Clear Bottles & Jars	3.22	0.00	3.60	3.27	3.31	3.79	0.00	4.36
Green Bottles & Jars	1.31	0.00	1.46	1.33	1.35	1.54	0.00	1.77
Brown Bottles & Jars	0.65	0.00	0.73	0.66	0.67	0.77	0.00	0.89
Other Glass	0.10	0.11	0.11	0.10	0.10	0.12	0.16	0.14
Food Cans	2.41	2.55	2.70	2.45	0.00	2.84	0.00	0.00
Beverage Cans	0.05	0.05	0.06	0.05	0.00	0.06	0.00	0.00
Batteries	0.05	0.05	0.06	0.05	0.05	0.06	0.08	0.07
Aerosols	0.20	0.21	0.22	0.20	0.21	0.24	0.31	0.27
Other Ferrous	0.96	1.01	1.07	0.97	0.98	1.13	1.47	1.29
White Goods	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Aluminium Foil	0.30	0.32	0.34	0.31	0.31	0.36	0.47	0.41
Beverage Cans - Aluminium	0.25	0.27	0.28	0.26	0.00	0.30	0.00	0.00
Aluminium Food Cans	0.10	0.11	0.11	0.10	0.00	0.12	0.00	0.00
Other	0.45	0.48	0.51	0.46	0.47	0.53	0.70	0.61
Garden Waste	15.13	15.96	16.91	15.37	15.57	0.00	0.00	20.50
Kitchen Compostable	10.11	10.66	11.29	10.27	10.40	11.91	15.59	13.69
Kitchen non-Compostable	5.03	5.30	5.62	5.11	5.17	5.92	7.76	6.81
Unclassified	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Combustible Particles < 10mm	2.16	2.28	2.42	2.20	2.22	2.55	3.34	2.93
non-Combustibles Particles < 10mm	2.16	2.28	2.42	2.20	2.22	2.55	3.34	2.93
TOTALS [wt%]:	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
tonnes/year	**74815**	**70941**	**66954**	**73649**	**72709**	**63493**	**48485**	**55218**
kg/hh/week	**15.66**	**14.85**	**14.01**	**15.41**	**15.22**	**13.29**	**10.15**	**11.56**

APPENDIX F: LIST OF PUBLICATIONS, ETC.

- Modelling Energy and Materials Flow for Evaluation of Alternatives for Processing Domestic and Commercial Wastes, P. Dacombe, V. Krivtsov, C. J. Banks, S. Heaven, Engineering Sustainability Journal (2005 - paper accepted for publication)
- Energy and Materials Flow Modelling of MSW: Options for Management of the Plastics Fraction in Household Waste, P. Dacombe, V. Krivtsov, C. J. Banks, S. Heaven, ISWA World Environment Congress and Exhibition, Rome, 17-21 October 2004, Rome, Proceedings
- Use of Energy Footprint Analysis to Determine the Best Options for Management of Glass from Household Waste, P. Dacombe, V. Krivtsov, C. J. Banks, S. Heaven, 'Sustainable Waste Management and Recycling: Challenges and Opportunities' Conference, Kingston University, 14-15 Sept. 2004, Proceedings
- Energy Footprint Analysis: Waste Management Options for the Processing of the Paper and Card Fraction of Household Waste, P. Dacombe, V. Krivtsov, C. J. Banks, S. Heaven, CIWM Exhibition, Torbay, June 2004, Poster Presentation June 2004
- Energy Footprint Analysis: Waste Management Options for the Processing of the Paper and Card Fraction of Household Waste, P. Dacombe, V. Krivtsov, C. J. Banks, S. Heaven, IWM & LCA Conference, Prague, April 2004, Paper and Poster Presentation
- Presentation of Energy Footprint project for Sustainable Waste Management MSc Module, University of Southampton (April 2004)
- Energy Footprint Analysis: Comparison of Waste Management Options for the Processing of the Glass and Paper/Card Components of Domestic Refuse, P. Dacombe, V. Krivtsov, C. J. Banks, S. Heaven, Eco-Efficiency for Sustainability Conference, Leiden, The Netherlands, 1-3 April 2004, Proceedings
- Analysis of energy footprints associated with recycling of glass and plastic - case studies for industrial ecology, V. Krivtsov, P.A. Wäger, P. Dacombe, P.W. Gilgen, S. Heaven, L.M. Hilty, C.J. Banks, Ecological Modelling, 174 (2004) 175-189
- Presentation made at FORWARRD meeting (September 2003)
- Mini-Waste meeting, Poster Presentation (October, 2003)
- Dacombe, P, Krivtsov, K, Lock, A, Modelling Energy and Materials Flow for Evaluation of Alternatives for Processing Domestic and Commercial Wastes, Waste Symposium 2003, Sheffield, July 2003, Poster Presentation
- Presentation made at NETSWAM meeting (July 2003)
- Dacombe, P, Krivtsov, V, Modelling Southampton's Waste – A Case Study for Industrial Ecology, CIWM Exhibition, Torbay, June 2003, Poster Presentation
- Krivtsov, V, Banks, C, Heaven, S, Sustainable Waste Management – The Energy Question, Wastes Management, vol. 34, January 2003
- Presentation made to Southampton Sustainability Forum (November 2002)
- Southampton University Press Release (October 2002)