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

Executive Summary

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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.

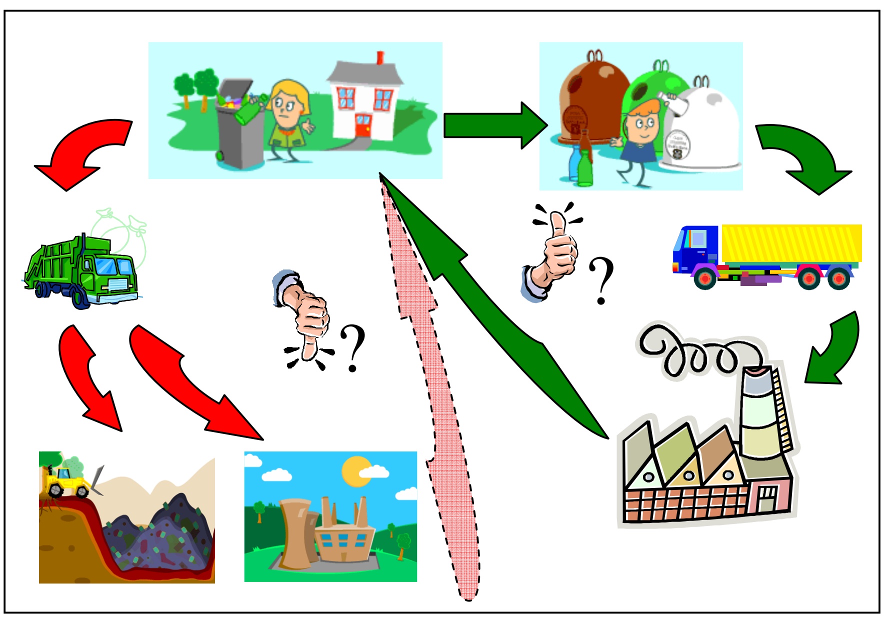

Figure 1: Simplified diagram of MSW management [1]

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 1, 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 1.

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: 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 2 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).

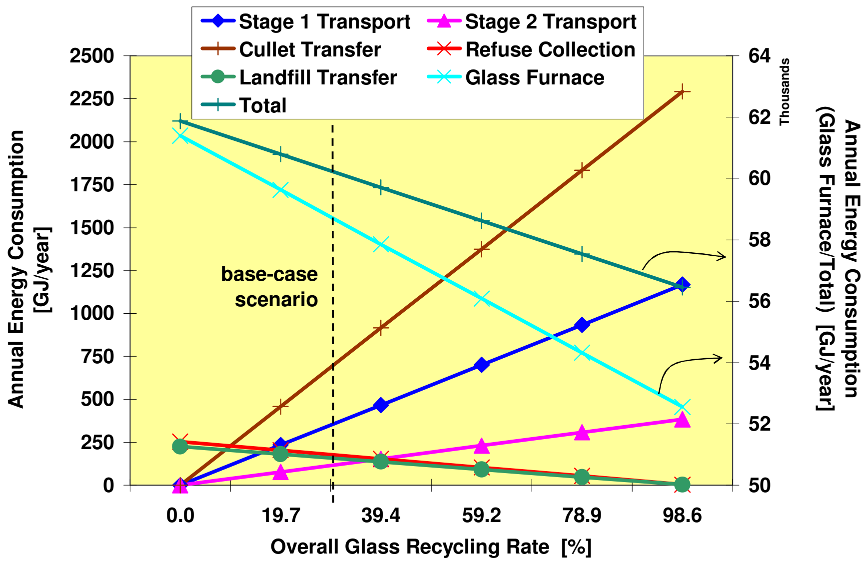

Figure 2: Effect of Glass Recycling on Energy Consumption

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 3 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.

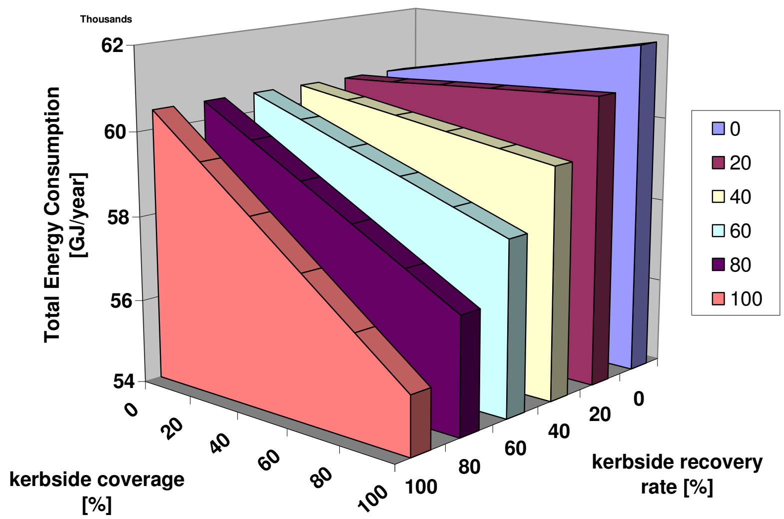

Figure 3: Effect of Introduction of a Kerbside Collection Scheme

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 4. 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).

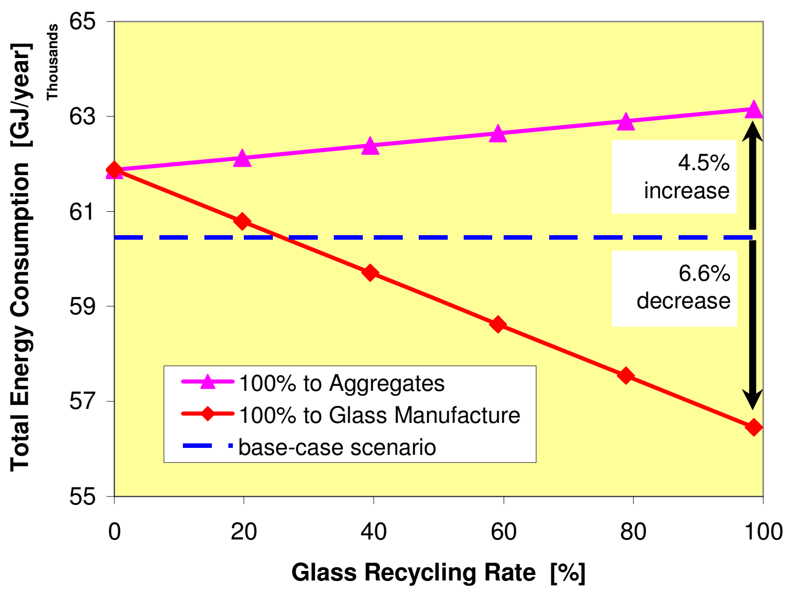

Figure 4: Comparison of Options for use of Recycled Glass

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.

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 5 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.

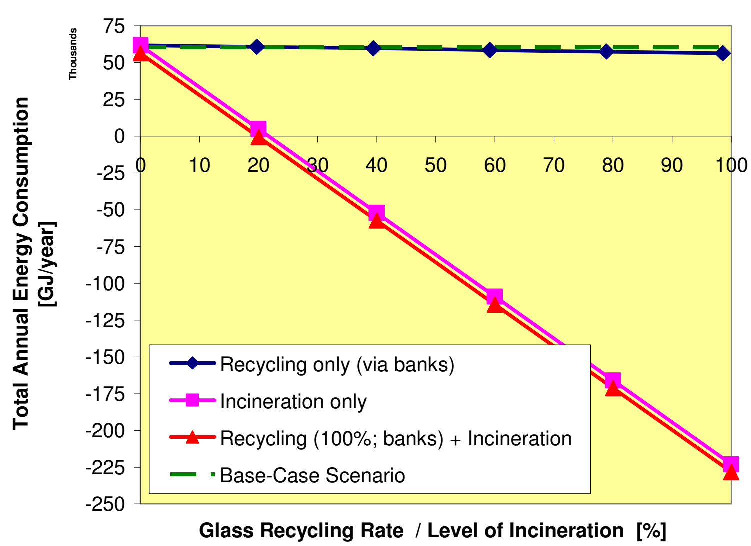

Figure 5: Effect of Incineration on Energy Consumption (Glass Fraction)

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 6 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.

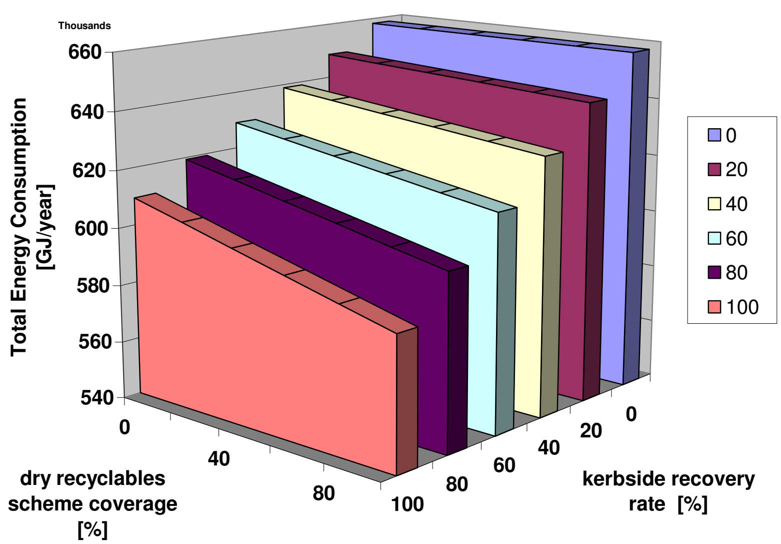

Figure 6: PaperChain versus Dry Recyclables Scheme

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 7. 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.

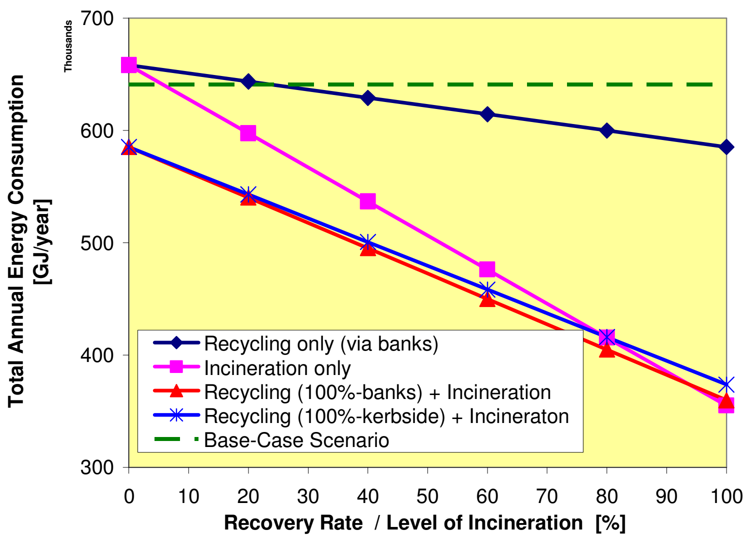

Figure 7 Comparison of Recycling and Incineration (Paper/Card Fraction)

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 8. 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.

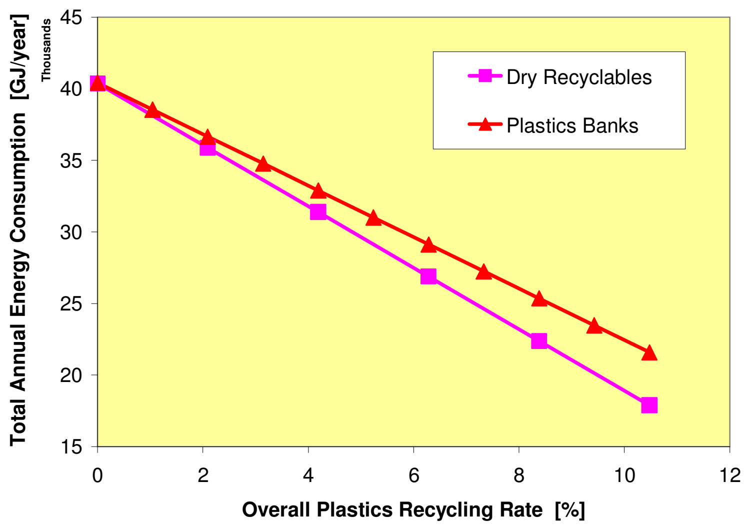

Figure 8: Effect of Recycling Method on Energy Consumption (Plastics Fraction)

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 9) 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.

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.

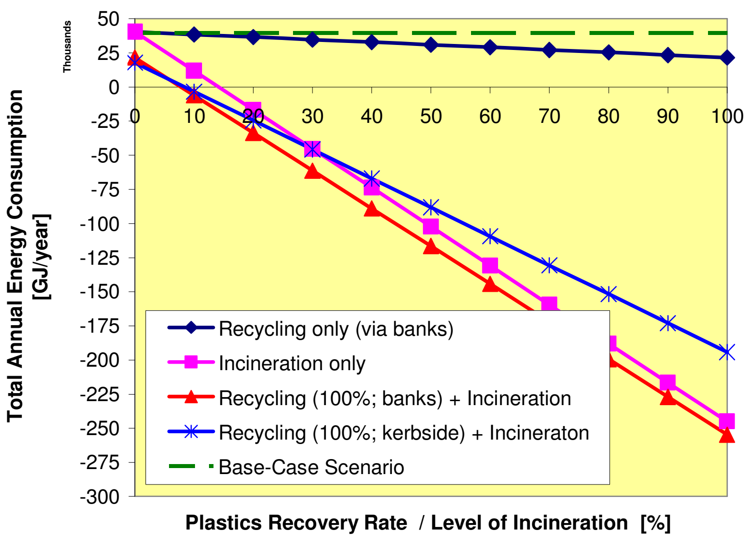

Figure 9: Comparison of Recycling and Incineration (Plastics Fraction)

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 10) 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.

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.

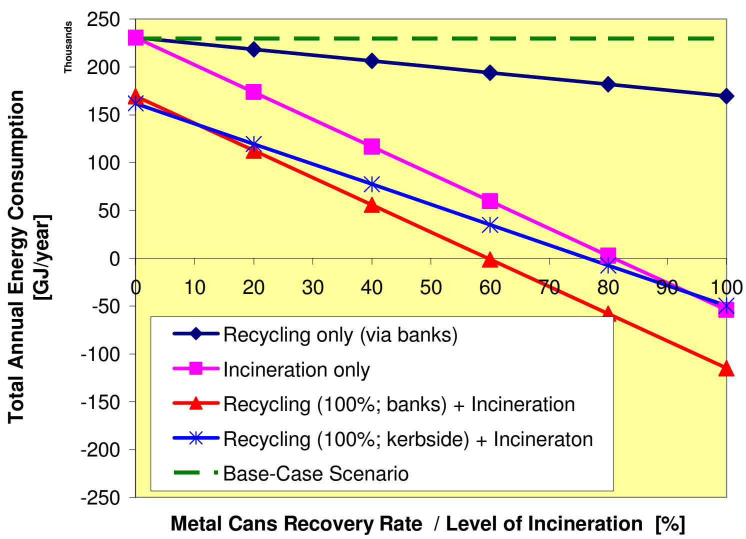

Figure 10: Comparison of Recycling and Incineration (Metals Fraction)

ORGANICS WASTE FRACTION

Centralised or Home Composting

Figure 11 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).

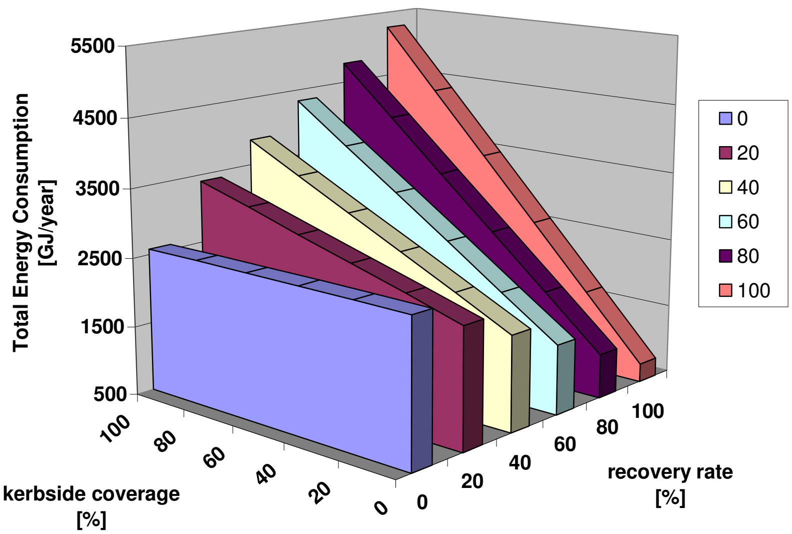

Figure 11: Replacement of Recycling via the Kerbside Garden Waste Scheme with Home Composting

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 12) 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.

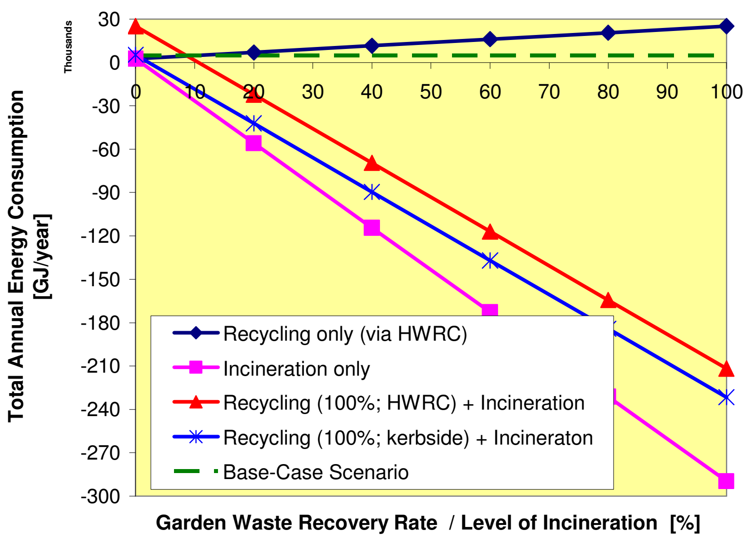

Figure 12: Comparison of Recycling and Incineration (Organics Fraction)

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 13). 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

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.

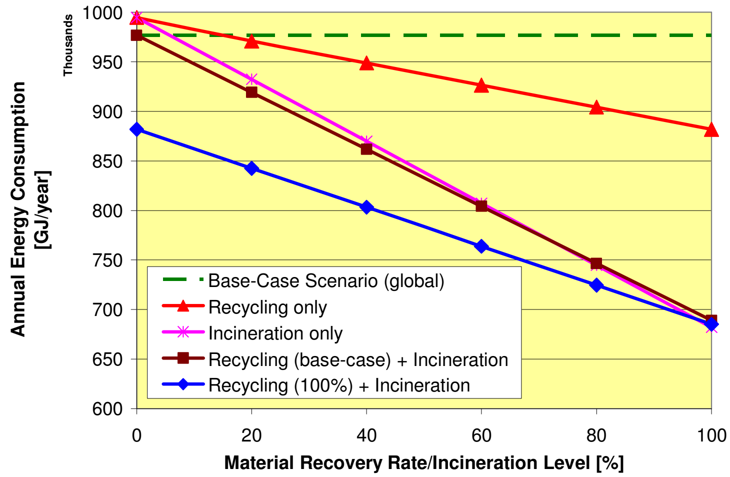

Figure 13: Energy Consumption for Global Waste Management Options

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 14 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).

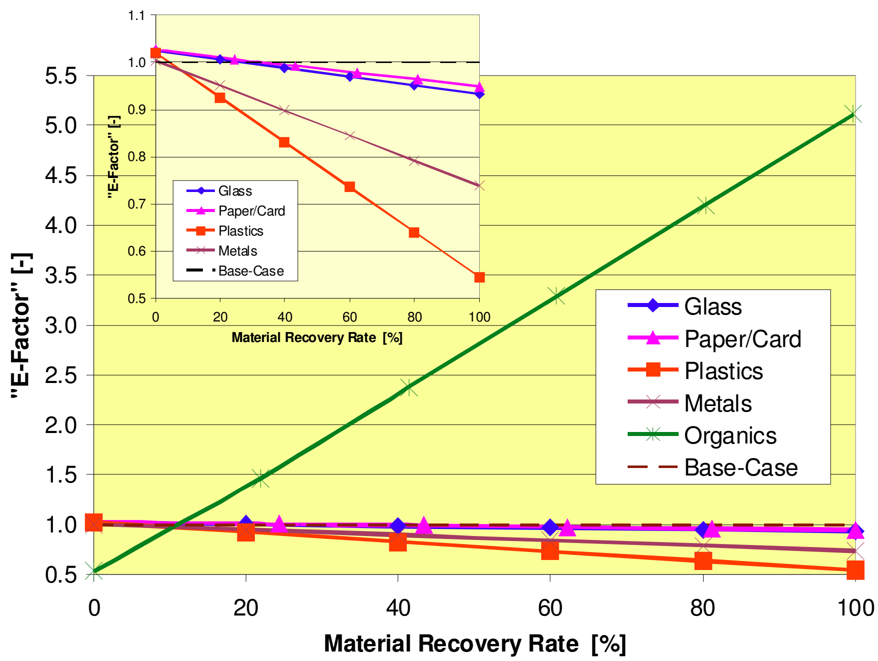

Figure 14: Waste Fraction Energy Factors

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 2, 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 2: 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] with acknowledgement to Rockware Glass for allowing use of images taken from the 'GLASSFOREVER' website