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WRT142 - EVALUATING THE COSTS OF ‘WASTE TO VALUE’ MANAGEMENT

FINAL REPORT

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EXECUTIVE SUMMARY

Scope

This project responded to the DEFRA call for research on ‘Understanding the True Costs of Waste Management’. The overall aim was to identify the cost components of the nodes and links within various material ‘waste-to-value’ supply chains. It is also important to recognise that, at this stage, the scope did not include the review or analysis of specific waste policies or strategies. However, certain relatively obvious deductions became apparent during the development of the underlying analysis process.

Approach

‘True’ costs in household waste management ‘supply chains’ concern the various combinations of methods, materials, processes and transport through which waste can pass and the resulting financial, environmental and social consequences.

To understand the costs of different waste management options it is necessary to examine the components of cost at each node and link, e.g. detailed energy costs, wage costs, infrastructure costs, material costs, etc. for each particular activity.

Unfortunately the term ‘supply chain’ can be misleading in this sense, given the considerable number of ways in which waste actually moves from origin to destination. There are no material supply chains as such, but a multiplicity of routes or channels each with significantly different costs. This is an important consideration for policy and cost analysis, particularly when allocating shared resources to different materials across facilities and transport.

Two sets of dynamics give rise to the complexity and variability in the supply channels and their associated costs. Firstly, the impact on costs of organisational objectives and behaviour, recycling targets, demography, politics, material markets and changes in operational costs. Secondly, the inter-relationship between material streams through the various logistic channels. This interlocking nature leads to considerable variability in costs. Variability requires the development of ranges for every aspect of the cost analysis. There is no single cost for anything for any length of time.

Given this complexity and variability in the waste-to-value ‘chains’, costs and interactions between material streams, it became necessary to use discrete event simulation for the analysis. A modular design approach was devised whereby a base model and hierarchical linked sub-models were built. This type of simulation enabled an analogous model of the waste management system to be developed so that its variability, dynamics and time-based behaviour could be directly addressed and changes in cost components and structure evaluated.

Output

The model calibrated and tested with 2003/04 waste data and subsequent analysis of the simulated results enabled various outputs and comments to be reported, amongst them were:

- The overall cost for the management of household waste in England was approx. £1.9 billion in 03/04.

- Costs in 03/04 are dominated by residual waste management (£1.5 billion), with an average of £74 per tonne, although recycling supply channels have a higher average cost per tonne (£105) and a total of £379 million. It should be remembered, however, that these are averages only and considerable variation exists between different channels and materials.
- Waste and reprocessing facility costs in that year accounted for £1.17 billion, whilst transport was estimated to cost £730 million.
- Household collection activities accounted for 84% of total transport costs.
- A comparative analysis of different recycling systems for a number of materials indicates that Bring and CA Sites frequently offer a cheaper route option compared with household collection. However, it should be noted that our cost estimates excluded private motoring costs, which to CA sites alone may be £200m (or £38 per tonne on average). Co-mingled dry recyclable household collections incur lower costs than sorted recyclable collections. However, when the cost of sorting co-mingled materials at an MRF is considered, the total supply route cost is not always cheaper.
- The analysis estimated the CO_2 equivalent emissions from household waste management. Total facility emissions, dominated by landfill, are estimated at 2.1m tonnes of CO_2 equivalent, or 88 kg CO_2 equivalent per tonne of waste processed on average. Transport emissions are also important (188,000 tonnes or 8kg/tonne processed). This excludes car trips to CA sites which are responsible for an estimated 133,000 tonnes of CO_2 equivalent (or 24kg/tonne processed). Recycling activities are estimated to have a net emissions benefit of nearly 2m tonnes (or 615kg/tonne recycled) achieved through the displacement of virgin materials.
- Financially cost efficient methods of moving ‘waste to value’ were not necessarily the most environmentally sound. For example, the CO_2 emissions per tonne of waste from delivering waste to CA sites was potentially 5 times greater than the CO_2 emissions per tonne of waste from kerbside collection.
- Based on our data assumptions the analysis estimates that a total of 248 million kms or 3.8 billion tonne kms are undertaken in the transport of household waste (excluding car trips to Bring and CA Sites). This mileage represents 38% of overall costs and results in 13% of total system carbon emissions (after calculating offsets for virgin material avoidance). Household collection transport is responsible for 47% of this mileage.
- In most instances the average cost of managing household waste exceeds any average revenues generated in the market. The greater part (71%) of overall costs is disposal to landfill, 48% of which is landfill tax. For recyclables 64% of costs were incurred prior to reprocessing, i.e. from Local Authority budgets. For some local authorities increasing targets and the resultant cost of waste management may require a trade-off between waste and other service provision, particularly as the marginal cost of extracting more material from a decreasing waste fraction increases.
- The supply of waste material for recycling from both commercial and municipal sources significantly exceeds domestic demand as is clearly evidenced by export statistics for waste materials. The project’s analysis of cost demonstrates that such a reliance on export demand continuing has systemic risk should export quantity decrease. Particularly, this is at a time when recycling targets are increasing the supply of materials, but domestic recycling capacity is decreasing, e.g. the recent closure of eight paper mills in 2006 and UK incineration capacity is limited.
- The business simulation of the waste ‘supply chain’ developed by this project shows there are a number of ‘supply chain’ players – Collection Authorities Disposal Authorities, DEFRA, other Central Government Departments, waste management

companies, waste merchants, and reprocessors each with their own aims, objectives and agendas. Self evidently, the scope, motivation and goals of each of these organisations often differ. Local Authorities are concerned with achieving tonnage targets, whereas reprocessors are more concerned with the quality of the input material. The general view is that the quality of the material resulting from tonnage-based targets is frequently not appropriate for domestic markets and as the cost analyses show this has a direct impact upon the value chain.
- The complex layout of the flows and variety of paths for waste materials shows that, based upon best logistical and supply chain management principles, the UK lacks a structure that can be cost effective and efficient. Viewed against good management practices the current system is fragmented by a governing political complexity that is driving dysfunctional actions and uncertain environmental and economic outcomes. In addition to unnecessary complexity, this confused structure and logistics architecture limits any real potential to be derived from economies of scale and the critical mass of material; e.g. to make rail or other alternative transport modes feasible.

Overall, by identifying the variety of routes and the cost components this research and the results of the simulation demonstrate the complexity of the ‘waste to value’ structure and the difficulties that this poses for its management, policy options and decision-making.

This project intentionally focussed upon identifying the overall architecture and the cost components. The analysis demonstrated that as a consequence of both the natural and inadvertent complexity, in order to understand the policy consequences of material mix, processes, social and environmental impacts it is necessary to comprehend the **whole** end-to-end ‘supply chain’ and the top-to-bottom reality of the economic and policy drivers involved.

Based upon the design analysis needed to establish the flows and costs it can be seen that the system is not in accord with proven supply chain principles. Indeed based upon logistics process re-design for a country of the UK’s size, and demographics these concepts suggest consideration should be given to establishing one central waste authority that could more effectively address the cost issues, the logistical structures, supply chain efficiency and the contracting specifications involved.

Implications

In order to meet the requirement of the project to identify the cost components the holistic treatment of the ‘supply chain’ processes was essential. As a direct consequence of this approach in the scoping of the model the analysis is able to indicate how there are significant and additional benefits to be gained from good logistics and supply chain principles, for example:

- Balancing the target driven supply push and domestic demand-pull, in terms of quantity and quality.
- Analysing the sensitivity to, and recognising the risk from changes to export levels.
- Exploration of the economies of scale and the critical mass of material that would make rail, inland waterways and offshore shipping more valid options, and possibly the use of alternative fuels (e.g. one train load is the equivalent to at least 40-50 truck loads, therefore rail offers potentially significant benefits).
- Investigation of strategically locating facilities to provide a service to the most people, irrespective of political boundaries.

- Synchronising and balancing flows and activities throughout the supply network.

Enhancements and Further Research

The underlying research and design analysis necessary to develop the 'supply chain' business model together with the outputs of the time-based simulation suggests fruitful areas of possible future research should include:

- Update the current analysis with data from 2005/06 (already underway) and include forecast factors (seasonalities and annual growth) to explore future trends and sensitivities.
- Further develop the analysis of environmental and social non-monetary costs and benefits. It would be possible to place monetary values on externalities e.g. emissions, to investigate and compare 'true' costs of different system and technological options.
- Re-calibrate the model to explore policy 'levers' at national, regional or local levels and 'what if' scenarios e.g. Regulatory Impact Assessment, PRN's, carbon taxes, PAYT. Best undertaken in liaison with and incorporating other policy analyses.
- Examine the potential from economies of scale, alternative technologies and transport modes.
- Examine the selective elimination of LA boundaries and the potential for cost reductions.
- Examine the Business options of pay as you throw (PAYT) or "paid to throw" systems.
- At macro-economic level, examine the structure of control, investment rate of return and full 'market' behaviour from a commercially operated public sector waste system. Such a re-design would enable the impact of 'commercial' best practices and incorporate legislation to be analysed within the model to explore the best overall combination.
- Investigate the transport implications of exported recyclables, i.e. costs, distance and emissions.
- Explore the potential costs and impact of including and managing household waste with C&I waste.
- Consider investigating supply chain economics for a smaller geographical area e.g. a county where it should be possible to obtain more detailed data, and therefore understand more clearly and compare the costs and benefits of operational activities and decisions.
- Development of the business modelling/simulation technique to enable local authorities to become 'intelligent customers' in the procurement of waste management services and contract evaluation. Provide a consistent approach to base case costing and 'public sector comparators'.

MAIN REPORT

1.0 INTRODUCTION

This report is structured in accordance with DEFRA requirements and report guidelines under the following headings:

- Background
- Scientific objectives and milestones
- Scope
- Methodology
- Results
- Implications of findings
- Possible future work

1.1 BACKGROUND

The DEFRA call for research on 'Understanding the True Costs of Waste Management' initiated this project. Our response is at Annex A.

Upon contract award the task was re-assessed and deliberately developed to be more extensive than anticipated in 2005 when a number of objectives that would be useful to know about 'waste to value' were first set out. A review of our analytic approach and the aims, led to a level of detail and complexity of a problem that we had not quite envisaged, but that in our view required inclusion and we decided to address the challenge of complexity directly.

The costs of sustainable waste management result from a number of processes and the transport links between facilities in the journey from 'waste to 'value'. Whether the waste arises from domestic, municipal, commercial or industrial sources, there are a multiplicity of potential logistic paths available and reasons for their selection (38,400 route options as a minimum).

Each of these individual paths has their own specific characteristics and costs. Individually, each represents a logistic process possessing multiple inter-related activities, i.e., collecting, consolidating, segregating, sorting, processing, manufacturing and transporting between activities, where;

- The performance of one part affects and is inextricably affected by that of the others.
- The alteration of certain activities can generate more change in system behaviour than others.
- Overall cost performance is dependent upon balance being achieved across activities.
- The weakest activity dictates the upper bound of performance.
- Optimum system performance is often not dependent upon the individual performance of each activity, but requires balance and co-ordination between them.
- Process cost includes the costs of the movement of information and money as well as product.

In order for the output of this project to contribute to decision-making, and to understand the 'waste to value' question, it was necessary to identify not only what it costs, but also why it costs what it costs. There are two sets of dynamics to consider. Firstly, the impact on cost variability of organisational objectives and behaviour, targets, demography, politics, material markets and changes in operational costs. Secondly, complexity resulting from the inter-relationship between material streams as they move through the various logistical channels.

In many areas there is a paucity of cost data, particularly where commercial sensitivities are (or are perceived to be) involved. In others areas cost data evidences very significant differences from place to place and for the same activity. Consequently we elected to use a method capable of handling the variability in the data and successive iterations without major re-design or re-compilation. Thus, to aid improvement by iteration we have consciously set out our assumptions in some detail specifically so that they can be revised as further data becomes available, for example the recently available Waste Data Flow for 2005/06.

1.2 SCIENTIFIC OBJECTIVES AND MILESTONES

1.2.1 Project Aim

The overall aim of the research was to identify and elucidate the behaviour of the cost components of the nodes and links within various material 'waste-to-value' supply chains.

Six specific research objectives were identified through which the primary aim was to be achieved. Each objective represented a phase in project development.

1.2.2 Phases and Secondary Objectives

Phase 1: Identify activity nodes and transport links for relevant material 'waste to value' supply chains, activities and processes.

Principal activities in this phase were to construct initial 'waste to value' supply chain models and investigate regional or process variations; review the scope of materials and activities; and report on the finalised in-scope activities, materials and transport links.

Phase 2: Identify and confirm cost components of activities and processes in each of the supply chains identified in Phase 1.

Principal activities in this phase were to identify high-level cost components and their contribution to overall activity costs for the nodes and links in the material supply chains; to increase the level of detail in this cost composition to the point where data can be reviewed and updated as circumstances change; report on the cost composition and relative costs.

Phase 3: Initial evaluation of 'waste to value' supply chain strengths and sensitivities based upon the costs components identified in Phase 2

Principal activities in this phase were to evaluate specific material supply chains with reference to the consequences of changes to cost components; factors that organisations can influence and exogenous factors; activity vulnerabilities and impacts resulting from exogenous change; and to provide a report on the initial evaluation and review.

Phase 4: Identify the scope for improvement in cost performance, priorities for action and system design, based upon the evaluation undertaken in Phase 3.

Principal activities in this phase were to evaluate specific material supply chains with reference to identifying priorities within organisations and supply chains where financial and technological investment would be most effective; the potential from alternative strategies (i.e. alternative process strategies, modes of transport operation, alternative fuels, etc.); their use as a tool for benchmarking performance; and to provide a report on the initial evaluation and review.

Phase 5: Determine any benefits of using Pathway Methodology or the Multiple Perspective Approach in improving cost performance or system design

The principal objective of this phase was to review alternative decision-making approaches and identify potential methods of evaluation; reassess Phase 4 results in the light of these alternative approaches; and report on their potential benefits.

Because of the decision to address complexity in developing the simulation model and the considerable benefits resulting, the finite time limitation meant this part of the project is not specifically reported.

Phase 6: Evaluate the potential of using the cost component approach in an on-line tool in conjunction with the project partners.

Principal activities in this phase were to consolidate and develop the scope for using the cost component approach as an on-line tool, establish its feasibility and possible structure, and to report accordingly.

This Phase is not reported. At the start of the project it was assumed that Excel would be used to undertake the cost analysis and as such would have potential for on-line applications. In the event a simulation model was used. While it may be possible to adapt this model for on-line application it would require the development of a further interface application to enable use.

1.2.3 Context

The process of research led to some interim observations that in themselves underpinned the design rationale for the approach to the cost analysis and modelling.

The market is considered to be the first point in the supply chain where the recovered material is of use either as a raw material for a manufacturing process or as a product i.e. the point where waste becomes of ‘value’ as a resource. For example, we consider the glass container manufacturers as the marketplace for waste glass, as they are using reprocessed glass cullet in a manufacturing process. Similarly, the paper mill is the market in the waste paper supply chain.

In this context, the term ‘*supply chain*’ is actually misleading. The reality is that the system is a network of links, enterprises and organisations employing combinations of integrated facilities within various ‘*supply chain*’ architectures (combinations of nodes and links), dealing with permutations of materials and vehicles (some several million possible options). It is thus misguided to think of an individual material supply chain, since it is only at the reprocessor stage that the transport and input to a facility and its output become close to being single material shipments.

Apart from reprocessors, the location of other facilities and their processes are not solely based upon a particular material type. Additionally, since facilities have a finite capacity, any change to the input mix or the quantity of a single material type will inevitably affect overall costs in general and other individual materials in particular.

This has very significant implications for the analysis, because at any stage in the supply network, changes to the quantity and quality of one material will affect the cost of other flows in the network. For instance, a decision to increase the quantity of plastic collected from households will impact the cost of collecting paper or glass and other materials (akin to 'marginal cost' analysis effects). Clearly, this is particularly important when it comes to matching strategic objectives with their likely impact upon and influence by operational costs.

It is also necessary to recognize that within waste management the word "quantity" has become synonymous with meaning the weight of waste. However, the density of materials in the waste stream differs greatly (plastic bottles compared to paper). Consequently the day-to-day random arisings mean that the maximum weight of the 'load' that will be moved will vary on each occasion because of the fixed volume of the truck. Thus, for example there is no simple relationship between costs and weight defined recycling targets.

This project was designed to inform debate and identify costs. Time allocated to this project did not include an examination of market forces and waste prices or any analysis of policy or control strategies. Where appropriate evidence is available, we have commented accordingly.

1.3 SCOPE

The project concentrated upon costing the waste supply routes arising from the municipal waste stream. This is where there is greatest pressure for Government and Local Authorities to increase recycling levels and where a greater understanding of cost is useful. Within this, we looked specifically at household waste. Recycling of Commercial and Industrial (C&I) waste is more developed and the associated costs are somewhat better understood partly because of the contractual nature of the relationships and partly because it is less complex.

A primary interest was in recycling where accumulated supply route costs are vital to the viability of the sector. An investigation of the costs associated with the value that might be extracted through MBT was not included at this stage, although, because of the design of the analytic approach it could be easily incorporated when the costs and the material flows and associated costs become available.

The waste categories considered were those for which published data was available in the DEFRA Municipal Waste Management Survey:

- Paper
- Corrugated and Card
- Plastic
- Glass (green, brown, clear and mixed)
- Steel packaging
- Aluminium packaging
- Mixed cans

- Organic waste for composting
- Textiles
- Scrap metal and white goods
- Other materials

The activities included in the study were:

- Household Waste Collection
- Bring Site
- Civic Amenity Site
- Transfer Station
- Materials Recycling Facility
- Landfill Site
- Incinerator
- Reprocessing (more than one stage for certain materials)
- Composting Facility

Household waste collection encompasses various methods with different operating processes, vehicle types and costs, and it was therefore necessary to consider the various types of collection separately. The following waste collection types were considered:

- Residual Waste Separate
- Integrated (co-collection)
  - Residual with co-mingled recyclables
  - Residual with sorted recyclables
  - Residual with compost
- Separate Collection
  - Co-mingled dry recyclables
  - Sorted dry recyclables
  - Compost
  - Scrap metal/white goods

Table 1 below shows the costs and other measures used in the analysis. The primary aim was to consider direct financial costs for each of the activities above. Additionally, it was considered important to investigate wider ‘external’ costs, the most important being carbon emissions. It would be possible within our analytical approach to consider other externalities such as air pollution, noise and accidents but this was beyond the scope of this project. A further measure considered was transport distances, which is receiving growing interest due to the greater distances that waste is often transported for recycling.

Transport Measures	Facility Measures
• Total transport costs • Labour costs • Fuel costs • Other variable costs, e.g. maintenance, tyres, etc • Other fixed costs e.g. insurance, licences, etc. • Distance • Transport carbon emissions	• Total facility costs • Labour costs • Plant and machinery costs • Utility costs • Other costs • Facility carbon emissions

Table 1: Transport and Facility Measures

2.0 METHODOLOGY

2.1 SIMULATION

Little previous work or research has attempted to econometrically replicate all the processes within the waste supply routes. Several studies have explored aspects of the ‘route to market’ of various waste materials; however this leads to major analytic difficulties in allocating resources to different materials across shared facilities. Since the central objective of the project is the analysis of the components of cost that comprise the waste to value network, we believed that it was essential to understand the various ways in which costs interact and accommodate this complexity in our approach.

Secondly, variability is present throughout the system; in the waste, the mix of materials at collection, vehicle types and the host of other variables. We recognised from numerous other ‘supply chain’ projects that accommodation of variability is a key and constant companion to supply chain analysis and process re-design, and this recognition drove the choice of computation methods towards discrete event simulation.

Given the underpinning factors above and the inevitable need for both an integrative and iterative approach, it was necessary to build our analytic model in such a way that change could be easily incorporated to drive refinement and facilitate ‘what if’ scenario development.

Consequently, it was the specific computational limitations of standard spreadsheet software (e.g. Lotus, MS Excel), which meant that it became necessary to utilise the analytical capabilities of discrete event simulation software to generate the cost and flow data.

The model flowcharts were therefore built from analysis of the physical waste network; specifically taking an end-to-end approach employing four basic stages:

- Collection, Sorting and Bulking. Largely the responsibility of Local Authorities, this reflects the action of transporting waste from the ‘door step’ to predominantly public sector financed Transfer Stations, and Material Recovery Facilities (MRFs). Members of the public also deposit waste at Civic Amenity Sites (CAS) and Bring Sites. Consequently these four basic processes are critical, as they represent the consolidation of waste from a disparate set of points reflective of the population demographic into larger consignments for onward movement.

- Reprocessing. Businesses make up the second stage processes where sorted materials are consolidated for either direct access to market or reprocessing for raw material input into manufacturing.

- Disposal. Operating in parallel and sequentially, landfill and incineration become the default processes for waste products not recovered for recycling and composting, or process residues.

- Market. The final process and where the revenue achieved initiates the ‘value chain’. Domestic and export prices drive behaviour back upstream because of the recovered material values in relation to virgin raw materials. Heavily influenced by Government and EU policies, these markets can be highly volatile.

2.2 MODEL DESIGN

The model design reflects these stages. The 'Base Model' is depicted below in Figure 1.

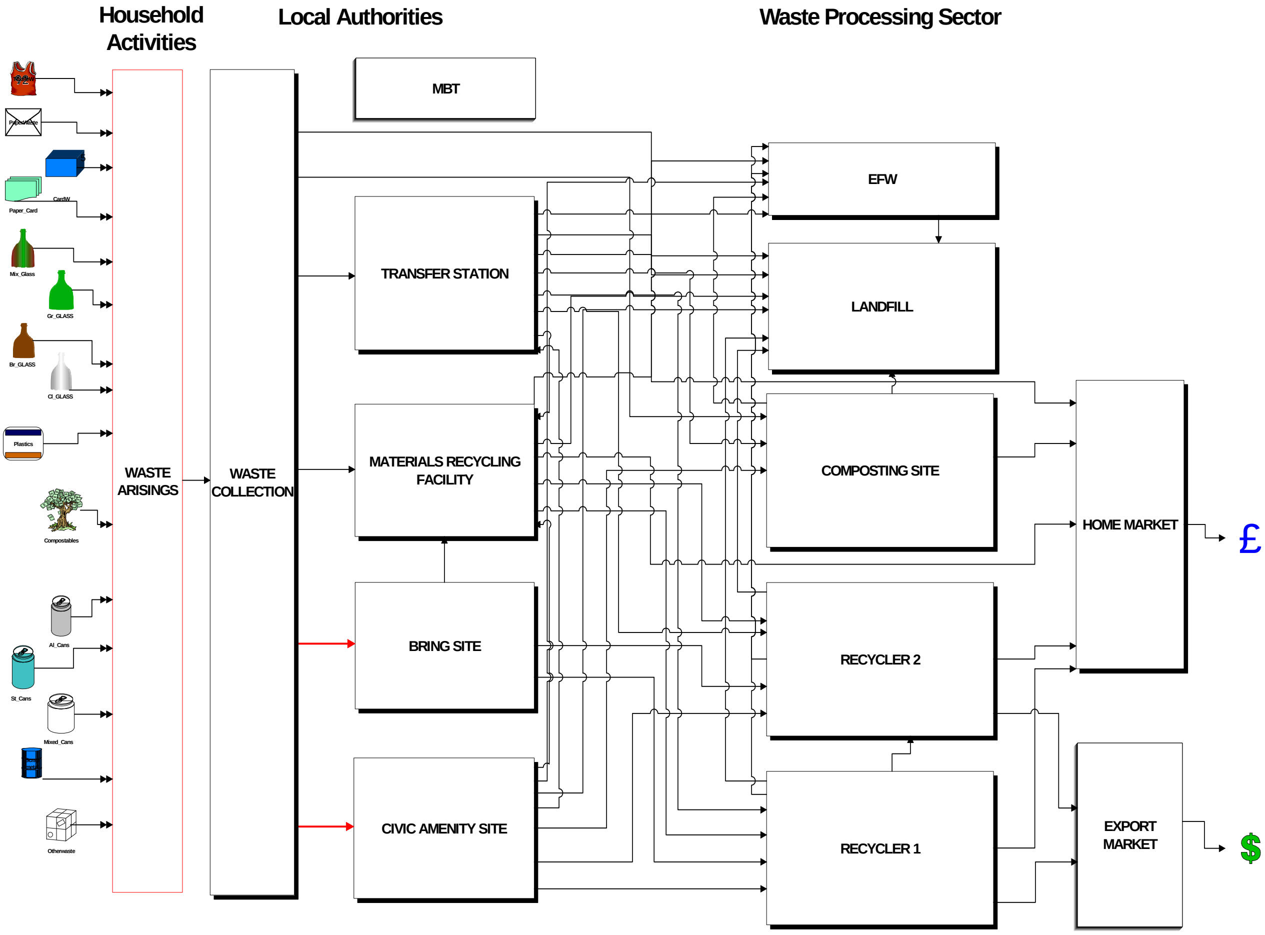

Figure 1: Base Model

As indicated earlier, it was an accepted principle of the project that iteration would be both a requirement and is inevitable. The simulation was calibrated with top-level statistics the basic high level flows were developed and refined by peer review.

Deliberately building the model in a modular format facilitated the construction of underlying sub-models that represented the major components of the 'base'.

Each of the sub-models tracks through the route options by material i.e. 'plastic' waste follows the route through facility options applicable to plastics; glass follows the correct pathway options for glass, etc.

Further advantages stem from the modular approach to the design by permitting easy revisions to the resources used to move and sort the waste entities.

The waste collection sub-model is shown below in Figure 2, by way of example. Schematics for each of the other sub-models are shown at Annex C.

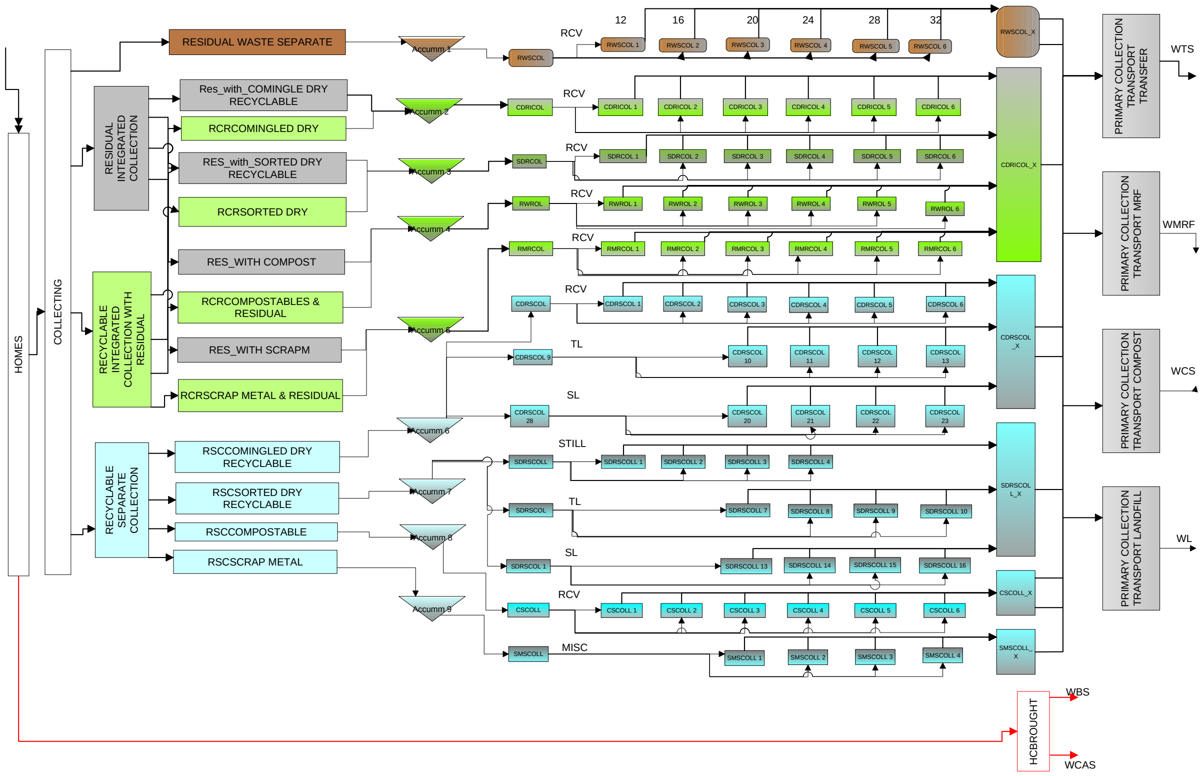

Figure 2: Household Collection Sub-Model

Not only do the various sub-models allow an accurate reflection of the physical supply network to be achieved but it also enables the necessary ‘counters’ to be inserted in the processes and links to record and report key performance indicators to measure the components of cost.

2.3 DATA SOURCES

The input cost data has been based upon other DEFRA and other Government statistics, reported projects, discussions with Local Authorities, industry experts, Trade Associations, surveys, questionnaires and our own information.

We have attempted to distil the information available appropriately and incorporate it effectively based upon the ‘best available’. Equally, we have set out our assumptions in detail in order that revisions are possible and the output can reflect the latest knowledge. The assumptions used in the analysis are presented at Annex F.

3.0 RESULTS

3.1 COSTS

3.1.1 Overall Costs

Our cost results focus on direct financial operating costs; for consistency depreciation has been included.

The simulation estimated the overall cost for the management of household waste in England to be £1.9 billion, as shown in Table 2 below. This includes collection, Bring and CA Sites, bulking, sorting, transport, disposal and reprocessing activities up to the first point where the material is exported or sold to the UK market as a usable raw material. It is based on 2003/04 waste management data. This figure excludes private car journey costs associated with transporting waste to Bring and CA Sites. There is uncertainty regarding the primary purpose of these trips, particularly for Bring Sites (e.g. people may be driving to a supermarket anyway). However, we estimate that private motoring costs to CA sites alone may be £200m.

Waste management costs are dominated by residual waste, accounting for 84% of total costs. Composting generates a relatively low average cost per tonne because a large proportion is taken to CA Sites rather than requiring home collection. Recycling is the most expensive option, with average supply route costs of £105 per tonne.

	Tonnes ('000)	Cost (£'000)	Average £/Tonne	% of Total Tonnes	% of Total Costs
Residual Waste - Landfill	18,112	1,348,053	74	75%	71%
Residual Waste - EfW	2,204	170,450	77	9%	9%
Composting	1,228	43,229	32	5%	2%
Recycling	2,673	335,302	105	11%	18%
Total	**24,217**	**1,897,034**	**78**		

Table 2: Household Waste Management Costs in England.

Notes: Costs include all supply route costs from household to final destination, except private transport costs for the householder in delivering to Bring and CA Sites.

Landfill costs include landfill tax.

Table 3 below shows that the operation of landfill sites accounts for 68% of all waste facility costs. However, a large proportion of landfill cost is landfill tax (48%).

Facility	Tonnes ('000)	Total Cost (£'000)	Average £/Tonne	% of Total Facility Costs
Transfer Station	9,738	97,802	10	8.4%
MRF	508	17,826	35	1.5%
Bring Site [a]	699	695	1	0.1%
CA Site	5,508	55,071	10	4.7%
Reprocessing Stage 1	874	25,790	30	2.2%
Reprocessing Stage 2	2,666	74,903	28	6.4%
Composting Facilities	1,354	15,568	11	1.3%
Landfill	18,112	791,000	44	67.8%
EfW	2,204	88,400	40	7.6%
Total		**1,167,055**		

Table 3: Facility Direct Operating Costs

Note: [a] Bring Site costs exclude collection costs which are illustrated in Table 4 below. Costs above include service and maintenance of the Bring Site.

Household collection accounts for 84% (£613m) of all transport costs in household waste management supply routes (see Table 4 below). This is due to the high quantity of waste being collected (18m tonnes) and a high average cost per tonne in comparison to other waste transport. Bring Site collections are also comparatively high with an average cost per tonne of £26/tonne across all materials collected (costs vary greatly by material).

Outbound Transport Activity	Tonnes ('000)	Total Cost (£'000)	Average £/Tonne	% of Total Waste Transport Costs
Household Collection	18,010	613,444	34	84.0%
Transfer Station	9,738	23,898	2	3.3%
MRF	508	3,862	8	0.5%
Bring Site	699	18,442	26	2.5%
CA Sites	5,509	51,379	9	7.0%
Reprocessing 1	874	4,992	9	0.7%
Reprocessing 2	1,762	11,914	6	1.6%
Composting Facility	861	1,513	2	0.2%
EfW	303	535	2	0.1%
Total		**729,979**		

Table 4: Transport Costs

3.1.2 Residual Waste Management

Landfill

Residual waste from the household waste stream arises from household collections, CA Sites and from rejected materials in MRFs and reprocessing activities. The majority of residual waste is sent to landfill sites (89%). Table 5 below shows the estimated total cost for the collection, transport and disposal of waste at landfills to be £1.35 billion. The resulting average supply route cost is estimated to be £74 per tonne.

Most residual waste is collected at households in separate collections, although some is co-collected on the same vehicles as recyclables or green waste. Household collection accounts for 32% of total costs, and landfill costs, including landfill tax account for 59%. The transport of residual waste from transfer stations and other facilities has a relatively small cost per tonne because these tend to be short distance trips in large vehicles with high vehicle utilisation.

At this stage the economic analysis has not attempted to remove from the cost data, elements which may be considered transfer payments. The most obvious example is landfill tax which clearly includes an element which is a transfer payment, however, there are similar elements contained within fuel tax, VAT, national insurance and other corporate taxes which may apply to contractors.

Activity	**Tonnes ('000)**	**Cost (£'000)**	**Average £/Tonne**	**% of Total Cost**
Household Collection				
Residual Waste Separate	13,869	415,509	30	30.82%
Integrated Collection with Co-mingled	243	9,500	39	0.70%
Integrated Collection with Sorted	143	5,658	40	0.42%
Integrated Collection with Compost	20	728	37	0.05%
Total Household Collection	*14,275*	*431,395*	*30*	*32.00%*
CA Site	3,221	32,477	10	2.41%
Transport from CA Site	3,221	12,775	4	0.95%
Transfer Station	6,665	67,015	10	4.97%
Transport from Transfer Station	6,665	12,306	2	0.91%
Transport from MRF	57	62	1	0.00%
Transport from Reprocessing Activities	172	358	2	0.03%
Transport from Composting Facilities	113	130	1	0.01%
Transport from EfW	303	535	2	0.04%
Landfill	18,112	791,000	44	58.68%
Total	**18,112**	**1,348,053**	**74**	

Table 5: Costs in Residual Waste Management Destined for Landfill
Note: Includes costs of transporting residual wastes from processes e.g. reprocessing

Energy from Waste (EfW)

In 2003/04, approximately 11% of residual waste from the household waste stream was incinerated in EfW plants. Table 6 below illustrates the estimated costs associated with collection, bulking, transport and incineration of that waste. Over 50% of the total supply route cost was at the EfW plant stage, whilst household collection accounted for over 30% of total cost. The average supply route cost is estimated to be £77 per tonne.

As noted above, the transport of residual waste from transfer stations and other facilities has a relatively small cost per tonne because these tend to be short distance trips in large vehicles with high load factors.

Activity	Tonnes (‘000)	Cost (£‘000)	Average £/Tonne	% of Total Cost
Household Collection				
Residual Waste Separate	1,664	49,839	30	29.24%
Integrated Collection with Co-mingled	65	2,525	39	1.48%
Integrated Collection with Sorted	38	1,504	40	0.88%
Integrated Collection with Compost	5	194	37	0.11%
Total Household Collection	*1,772*	*54,062*	*31*	*31.72%*
CA Site	399	4,023	10	2.36%
Transport from CA Site	399	2,256	6	1.32%
Transfer Station	1,779	17,885	10	10.49%
Transport from Transfer Station	1,779	3,740	2	2.19%
Transport from MRF	7	13	2	0.01%
Transport from Reprocessing Activities	21	49	2	0.03%
Transport from Composting Facilities	14	23	2	0.01%
EfW	2,204	88,400	40	51.86%
Total	**2,204**	**170,450**	**77**	

Table 6: Costs in Residual Waste Management Destined for EfW
Note: Includes costs of transporting residual wastes from processes e.g. reprocessing

3.1.3 Composting

It is estimated that the cost of collecting and composting 1.35m tonnes of green waste from households is £43.2m (see Table 7 below). 71% of compostables from households are collected through CA Sites, against 29% from kerbside collections. Conversely, the total cost of green waste household collection is greater than CA Site costs (£11.5m against £9.3m), illustrating the higher cost per tonne in household collections.

As above, there are relatively low costs per tonne for some short distance transport trips.

Activity	Tonnes (‘000)	Cost (£'000)	Average £/Tonne	% of Total Cost
Household Collection				
Integrated Collection with Residual Waste	12	440	37	1.0%
Separate Compost Collection	377	11,100	29	25.7%
Total Household Collection	*389*	*11,540*	*30*	*26.7%*
CA Site	964	9,290	10	21.5%
Transport from CA Site	964	4,808	5	11.1%
Transfer Station	52	526	10	1.2%
Transport from Transfer Station	52	138	3	0.3%
Compost Facilities	1,354	15,568	11	36.0%
Transport from Composting Facilities	735	1,360	2	3.1%
Total	**1,354**	**43,229**	**32**	

Table 7: Costs in the Management of Household Waste for Composting

3.1.4 Recycling

Table 8 shows the total cost of household waste recycling supply chains is estimated to be £335m. This includes household collection, Bring and CA Sites, MRFs, transfer stations, transport and reprocessing activities. The average supply route cost across all materials is £105 per tonne.

Household collection accounts for 35% of total costs. Over 1 million tonnes of recyclables are collected in sorted systems (i.e. materials are sorted at the kerbside), at a total cost of over £96m and an average cost of £90 per tonne. Co-mingled collections are cheaper than sorted collections averaging £40 per tonne. Some 372,000 tonnes of co-mingled recyclables are collected in separate collections at a total cost of £14.8m. However, just over 500,000 tonnes co-mingled recyclables must then be sorted at MRFs which are estimated to cost nearly £18m (includes co-mingled recyclables from Bring and CA Sites). It costs £35 per tonne on average to process waste at MRFs.

Additionally, a small quantity of recyclables (sorted and co-mingled - approximately 114,000 tonnes) is co-collected with residual waste in integrated loads.

Reprocessing activities account for 30% of total recycling supply chain costs. For some materials, a number of reprocessing stages exist e.g. aluminium and steel cans, whilst others only move through one reprocessing stage e.g. glass and paper.

Transport of recyclables from CA Sites and Bring Sites can be expensive in terms of cost per tonne, because for many bulky materials such as plastic bottles, only low volume loads are possible and long distance trips are potentially necessary.

Activity	Tonnes ('000)	Cost (£'000)	Average £/Tonne	% of Total Cost
Household Collection				
Integrated Collection Co-mingled with Residual	69	2,774	39	0.8%
Integrated Collection Sorted Recyclables with Residual	45	1,838	40	0.5%
Co-mingled Separate Collection	372	14,800	40	4.4%
Sorted Dry Recyclables (separate collection)	1,065	96,400	90	28.8%
Scrap Metal/White goods collection	20	635	32	0.2%
Total Household Collection	*1,571*	*116,448*	*74*	*34.7%*
CA Site	926	9,282	10	2.8%
Transport from CA Site	926	31,540	34	9.4%
Bring Site	699	695	1	0.2%
Transport from Bring Site	699	18,442	26	5.5%
Transfer Station	1,243	12,376	10	3.7%
Transport from Transfer Station	1,243	7,713	6	2.3%
MRF	508	17,826	35	5.3%
Transport from MRF [a]	444	3,787	9	1.1%
Reprocessing (Stage 1)	874	25,790	30	7.7%
Transport from Reprocessing Activities (Stage 1) [b]	504	4,919	10	1.5%
Reprocessing (Stage 2)	2,666	74,903	28	22.3%
Transport from Reprocessing Activities (Stage 2) [b]	1,820	11,581	6	3.5%
Total	**3,196**	**335,302**	**105**	

Table 8: Costs in the Management of Household Waste for Recycling

Notes:
[a] Excludes transport of residual waste (included in Tables 5 and 6 above) [b] Excludes transport of residual waste (included in Tables 5 and 6 above), or transport of exported materials

Table 9 overleaf shows the costs of recycling activities at each stage in the supply chain by material type. Materials do not pass through all facility stages shown in the table, nor indeed necessarily in the order shown.

Paper and card recycling carries the largest overall costs because of their volume. The cost of collecting and reprocessing paper from households is estimated to be £140m. Recycling of 'other' materials (£48m), glass (£43m) and scrap metal/white goods (£38m) have the next highest overall costs. The collection and delivery to MRFs of co-mingled materials is estimated to cost approximately £21m.

	Cost (£'000)													
	Household Collection	Transfer Station	Transport from Transfer Station	MRF	Transport from MRF	Bring Site	Collection from Bring Site	CA Site	Transport from CA Sites	Reprocessor Stage 1	Transport from Reprocessor 1	Reprocessor Stage 2	Transport from Reprocessor 2	Total
Green glass	2,556	294	162	1,252	121	102	2,461	81	80	-	-	4,498	1,017	12,624
Brown glass	440	35	20	251	18	16	378	10	15	-	-	861	185	2,229
Clear glass	1,506	179	93	761	90	53	1,303	35	43	-	-	2,813	629	7,505
Mixed glass	10,605	1,210	666	-	-	199	4,775	350	482	-	-	1,787	252	20,326
Paper	54,012	6,038	4,674	6,470	1,529	193	2,779	461	405	-	-	13,092	3,362	93,015
Card	1,333	176	107	681	209	6	466	770	3,274	-	-	2,158	527	9,708
Mixed paper/card	22,249	2,701	704	-	-	66	1,536	232	289	-	-	6,366	1,287	35,429
Steel cans	96	12	29	3,790	1,231	0	7	-	-	1,313	202	7,817	156	14,652
Aluminium cans	373	43	131	1,195	223	-	-	1	8	444	146	3,914	59	6,538
Mixed cans	1,902	205	159	-	-	8	356	70	217	-	-	-	-	2,918
Plastics	669	79	121	3,393	361	5	2,110	28	228	-	-	10,494	184	17,670
Textiles & footwear	1,023	102	148	33	6	31	1,219	181	418	1,711	228	356	63	5,518
Scrap metal/white goods	635	218	32	-	-	2	9	4,400	1,073	14,206	2,262	13,186	2,457	38,482
Other materials	1,474	148	230	-	-	-	-	2,525	24,384	8,117	2,082	7,562	1,404	47,926
Co-mingled	17,574	934	437	-	-	14	1,042	137	625	-	-	-	-	20,763
Total	**116,448**	**12,376**	**7,713**	**17,826**	**3,787**	**695**	**18,442**	**9,282**	**31,540**	**25,790**	**4,919**	**74,903**	**11,581**	**335,302**

Table 9: Total Costs of Recycling at Each Supply Chain Stage by Material Type

Notes:
Material costs exclude co-mingled costs, which are listed separately in the table. It is difficult to separate out costs by material in co-mingled collections. At the MRF stage, when co-mingled materials are separated, costs are attached to the respective material streams.
The relatively high transport cost for 'other' materials from CA Sites is partly due to the potential long distances that certain specialised wastes such as WEEE and batteries may have to be transported. A random uniform distribution was used to determine trip distances based on the maximum and minimum distances for other types of trip.

Figures 3 to 5 below illustrate the various recycling supply routes for paper, glass and plastic bottles respectively. The dots and arrows indicate nodes and links in the supply routes. At each node and link, estimated costs per tonne based on the simulation results are shown, with the total supply route cost shown at the right hand side of each example. It is important to stress that these are illustrative costs based on averages across the entire country over a year. In reality, costs through each route may vary significantly.

Figure 3 shows that Bring and CA Site routes offer the cheapest supply route option for paper. Sorted household collections are more expensive than co-mingled collections at the collection stage and as a supply route option. However, the quality of paper produced in an MRF is lower than from sorted collections and, as a consequence attracts a lower selling price.

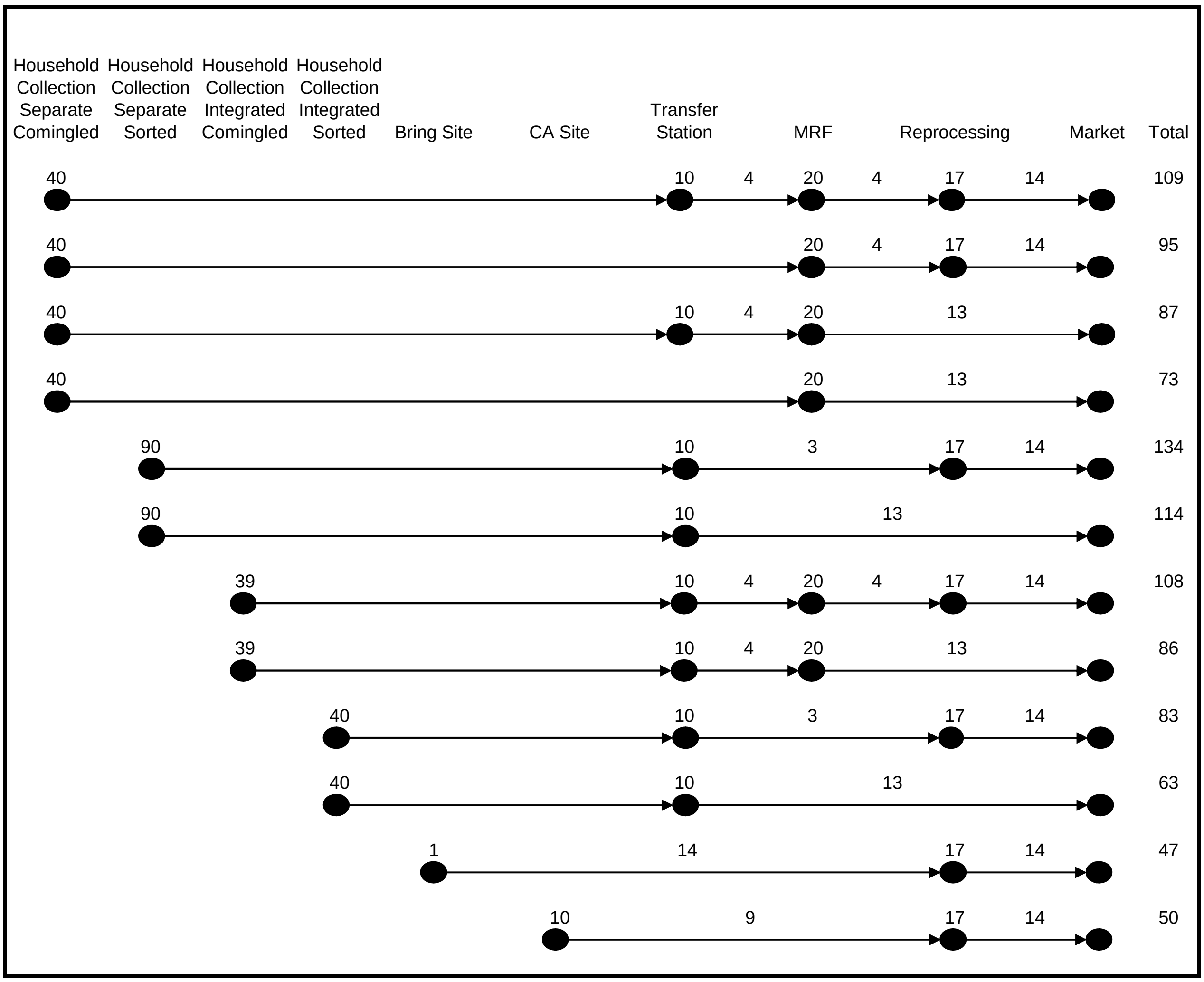

Figure 3: Comparison of Paper Recycling Supply Route Costs (£/tonne)
Note: CA and Bring Site costs exclude private motoring costs.

The difference in supply route costs between the highest at £109 and the lowest at £47 evidences the wide range of costs arising from the choice of logistical route.

Bring and CA Sites also offer the cheapest supply route options for recycling of glass (see Figure 43 below). There is little difference in cost between co-mingled and sorted household collection supply routes for glass.

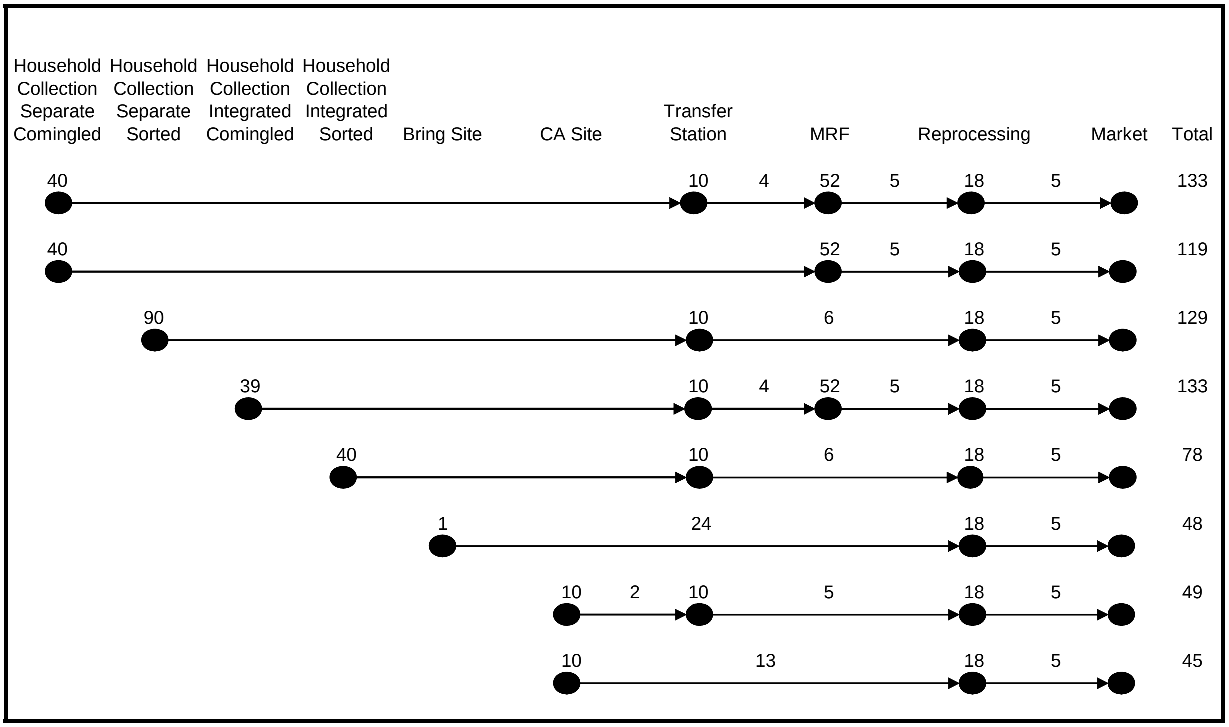

Figure 4: Comparison of Glass Recycling Supply Route Costs (£/tonne)

Notes:
Costs are for colour separated glass destined for glass manufacturing markets
CA and Bring Site costs exclude private motoring costs.

Again, difference in supply route costs between the highest at £133 and the lowest at £45 evidences the wide range of costs arising from logistical choice.

The supply routes for the various methods of plastic bottle collection and reprocessing are illustrated in Figure 5 below. Costs are significantly higher than for glass and paper, due in part to the high cost of reprocessing. Additionally, plastic is a low density material, which affects the cost of sortation and transport.

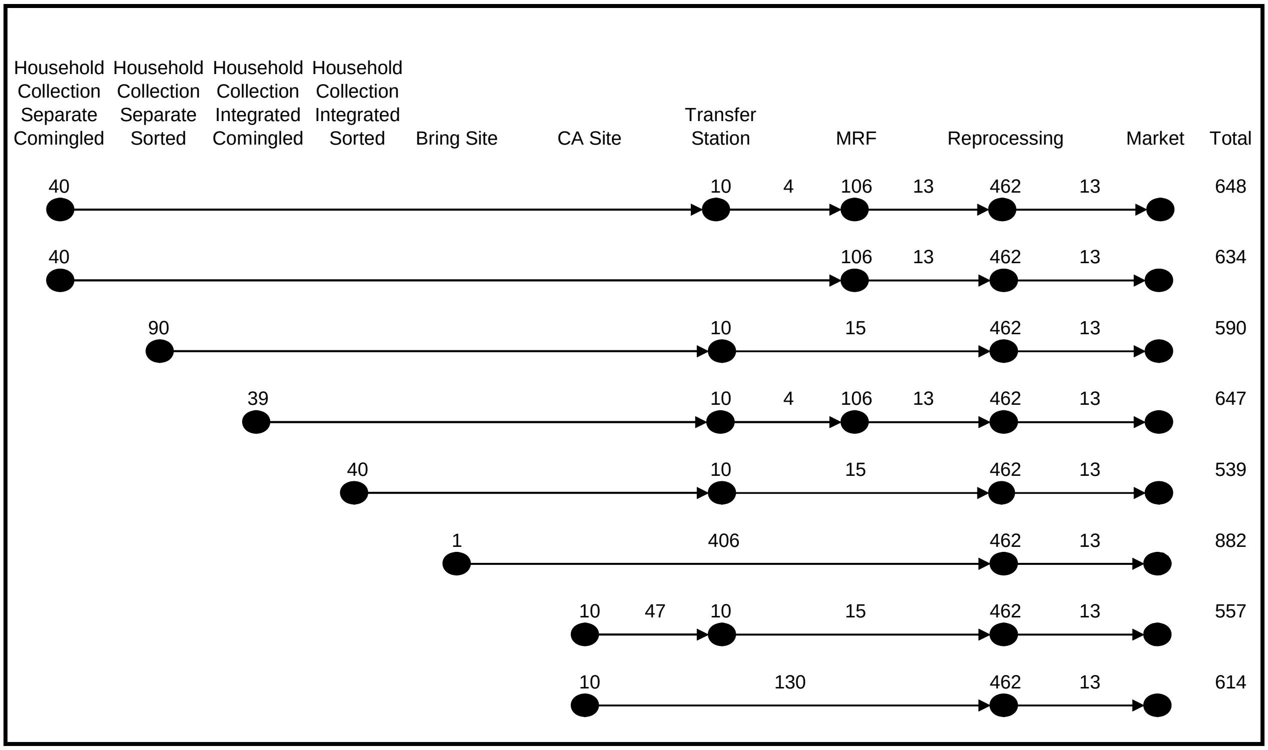

Figure 5: Comparison of Plastic Recycling Supply Route Costs (£/tonne)
Note: CA and Bring Site costs exclude private motoring costs.

3.2 COMPONENTS OF COST

The key objective of the project was to consider not only the overall costs of waste management, but also the components of those costs. Table 10 below shows the estimated components of costs at each type of facility. Care must be taken in viewing these figures since for some facilities data has proved difficult to obtain. Our data is set out in our assumptions and can be readily revised should improved estimates become available.

Landfill tax makes up a large proportion of total landfill costs, which in turn contributes a significant proportion of total costs.

Labour costs are the most important for most facility types demonstrating the labour intensive nature of the processes. Plant and machinery costs are also important, particularly at landfills and in reprocessing activities.

Process Activities	Labour	Plant/ Machinery	Utilities	Other Costs	Landfill Tax	Total
	Costs (£'000)					
Transfer Station	39,411	17,795	5,911	34,686	-	97,802
MRF	11,951	1,944	354	3,576	-	17,826
Bring Site	174	174	174	174	-	695
CA Site	31,701	7,175	2,238	13,957	-	55,071
Reprocessing (Stages 1 & 2)					-	
Aluminium cans	1,266	906	1,379	808	-	4,359
Glass	3,486	2,988	996	2,490	-	9,959
Paper/card	10,159	4,107	432	6,917	-	21,616
Other	6,482	3,474	1,235	4,488	-	15,679
Plastic	2,099	3,673	2,623	2,099	-	10,494
Scrap metal	10,632	5,864	3,581	7,315	-	27,392
Steel cans	2,962	2,126	1,981	2,062	-	9,130
Textiles	928	432	70	636	-	2,066
Composting	5,846	6,415	1,419	1,887	-	15,568
Landfill	123,196	164,262	41,065	82,131	380,346	791,000
EfW	17,680	44,200	17,680	8,840	-	88,400
Total	**267,974**	**265,534**	**81,138**	**172,064**	**380,346**	**1,167,055**

Table 10: Facility Component Costs

Figure 6 shows the overall breakdown of component costs for facilities shown in Table 10 above. Landfill tax is the most important cost (32%), followed by labour and plant & machinery (both 23%).

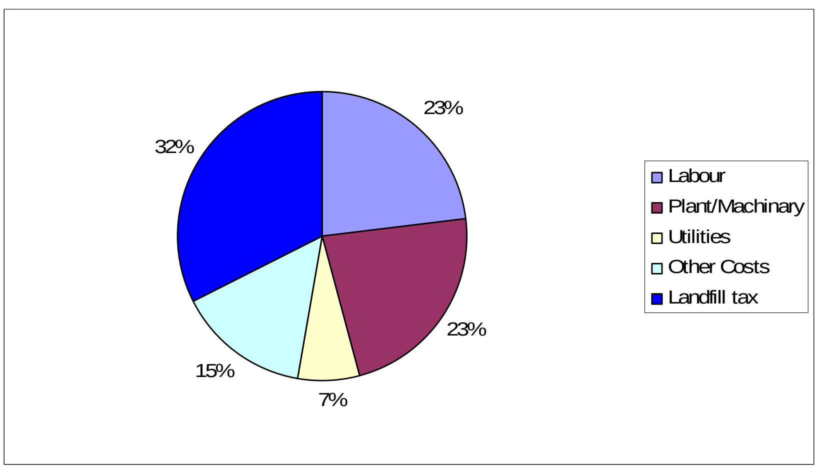

Figure 6: Components of Cost for Total Facility Costs

Table 11 below shows the components of transport costs in the waste supply chain. Labour costs are the most important overall, costing £389m. This is a consequence of labour intensive household collection activities where multi-personnel crews are utilised. For other transport activities in the supply chain, fuel is the most important cost. Overall fuel costs amount to approximately £98.5m.

	Cost (£'000)				
Outbound Transport Activities	**Labour**	**Fuel**	**Other Variable Costs**	**Other Fixed Costs**	**Total**
Household Collection	364,048	63,512	72,895	112,989	613,444
Transfer Station	4,541	8,603	2,390	8,364	23,898
MRF	367	695	193	676	1,931
Bring Site	5,682	4,947	1,677	6,136	18,442
CA Sites	11,659	15,619	5,221	18,880	51,379
Reprocessing 1	38	73	20	71	202
Reprocessing 2	2,276	4,313	1,198	4,193	11,980
Composting Facility	287	545	151	529	1,513
Transport from EfW	102	193	54	187	535
Total	**389,000**	**98,499**	**83,799**	**152,025**	**723,324**

Table 11: Transport Component Costs

Figure 7 illustrates the overall breakdown of transport component costs. Labour accounts for 53% of total transport costs. Other fixed costs (excluding wages) such as insurance, licences and establishment costs account for 21% of total costs. Fuel costs are 14% of total costs, although as mentioned above, this proportion is much higher in transport activities other than household collection.

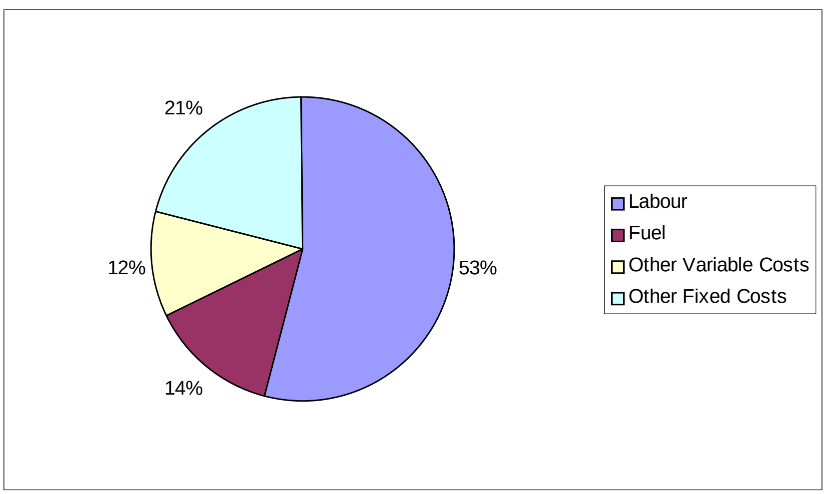

Figure 7: Components of Cost for Total Transport Costs

Tables 12 and 13 below show the components of facility and transport costs for recycling activities, by material type.

	Costs (£'000)				
	Labour	Plant/ Machinery	Utilities	Other Costs	Total
Green glass	2,603	1,577	522	1,525	6,227
Brown glass	490	296	98	289	1,173
Clear glass	1,599	977	322	943	3,841
Mixed glass	1,364	852	316	1,014	3,546
Paper	13,219	4,404	822	7,809	26,254
Card	1,987	619	100	1,085	3,791
Mixed paper/card	4,230	1,748	316	3,070	9,365
Steel cans	5,516	2,544	2,057	2,815	12,932
Aluminium cans	2,094	1,041	1,405	1,057	5,598
Mixed cans	125	48	17	93	283
Plastics	4,429	4,059	2,698	2,812	13,999
Textiles & footwear	1,103	485	92	734	2,413
Scrap metal/white goods	13,254	6,477	3,773	8,508	32,013
Other materials	7,996	3,830	1,346	5,180	18,353
Co-mingled	459	191	66	369	1,085
Total	**60,470**	**29,148**	**13,949**	**37,305**	**140,872**

Table 12: Total Recycling Facility Component Costs by Material Type

	Costs (£'000)				
	Labour	Fuel	Other Variable Costs	Other Fixed Costs	Total
Green glass	2,771	1,352	625	1,649	6,397
Brown glass	463	221	103	269	1,056
Clear glass	1,595	772	359	937	3,664
Mixed glass	9,004	2,586	1,666	3,523	16,779
Paper	39,675	8,546	6,815	11,725	66,761
Card	1,929	1,569	590	1,829	5,917
Mixed paper/card	16,123	2,960	2,659	4,322	26,064
Steel cans	374	592	173	582	1,720
Aluminium cans	363	233	95	249	940
Mixed cans	1,495	366	265	509	2,635
Plastics	1,286	927	350	1,109	3,672
Textiles & footwear	1,256	693	302	854	3,105
Scrap metal/white goods	1,444	2,127	682	2,216	6,470
Other materials	7,343	8,764	2,963	10,503	29,573
Co-mingled	11,451	2,537	2,354	3,336	19,678
Total	**96,572**	**34,244**	**20,003**	**43,612**	**194,430**

Table 13: Total Recycling Transport Component Costs by Material Type

3.3 COST AND VALUE IN RECYCLING SUPPLY ROUTES

This section reports on a number of illustrative, supplementary scenarios. Examples are provided for a number of materials to demonstrate potential uses of data from the simulation. These results could be repeated for any type of material.

Figures 8 to 11 each show the cumulative costs of various paper recycling supply routes against values of materials. In the charts below, values from co-mingled collections are based on mixed paper prices, where quality tends to be poorer and therefore price received is likely to be lower: other paper values are based on news/pams prices. Prices are from October 2006, and are sourced from Letsrecycle.com. The charts indicate two value stages in the chain. The first value arises where a price is paid by a reprocessor (waste paper merchant) to suppliers of materials (e.g. local authorities). The second value is the price paid by a paper mill to a waste merchant.

An analysis of revenues to Local Authorities has not been included. This is complicated by differing contractual arrangements with reprocessors and as a consequence any revenue generated has significant variation. For example, some reprocessors may have arrangements where PRN revenues are shared with supplier.

3.3.1 Paper

Four key supply routes are compared; paper from sorted household collection, co-mingled collection, Bring Site and CA Site. Paper collected from sorted household collections has the highest overall supply route costs due to the high cost of collection. Paper collected through co-mingled has a lower supply route cost. Co-mingled collections are cheaper than sorted collections, although this is partly offset by the cost of sorting recyclables at the MRF and the fact that the material is likely to receive a lower price.

Bring Site and CA Sites offer the cheapest overall supply route cost, although they do not take into account the cost to the householder of delivering the waste to the sites.

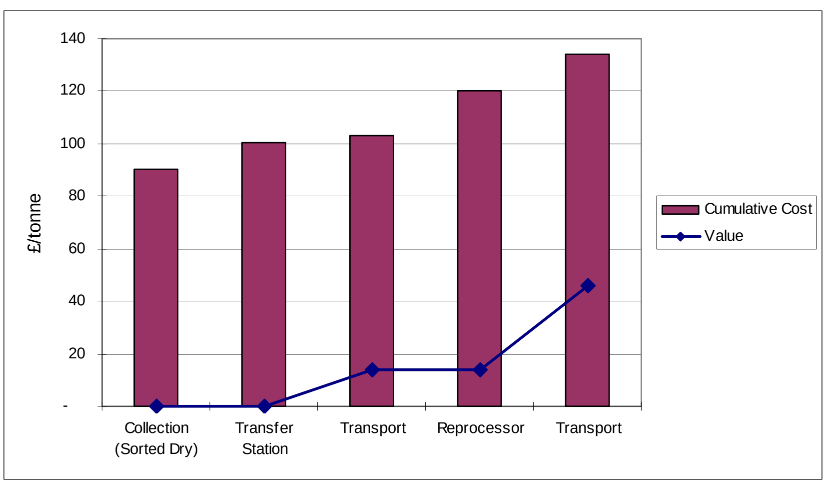

Figure 8: Cost v Value: Paper from Sorted Household Collections

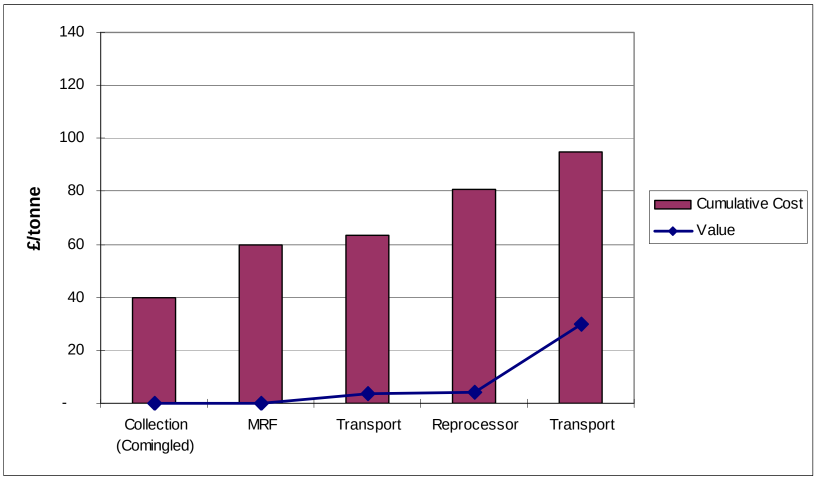

Figure 9: Cost v Value: Paper from Co-mingled Household Collections

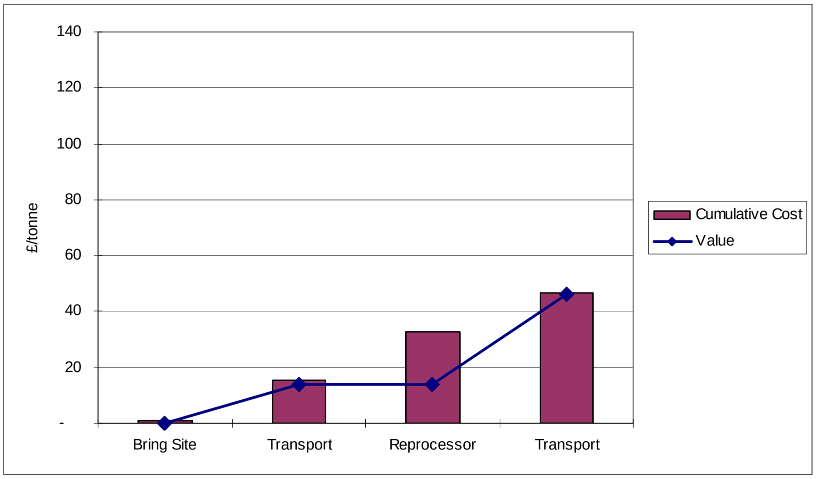

Figure 10: Cost v Value: Paper from Bring Sites

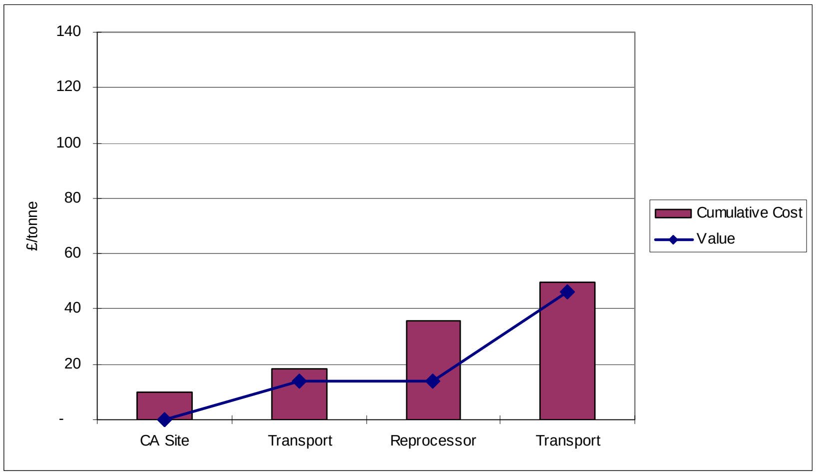

Figure 11: Cost v Value: Paper from CA Sites

Figure 12 below shows the relationship between tonnes processed and total cost of processing at each stage in the paper and card recycling supply network. It shows the relatively high cost of household collection for the quantity actually collected.

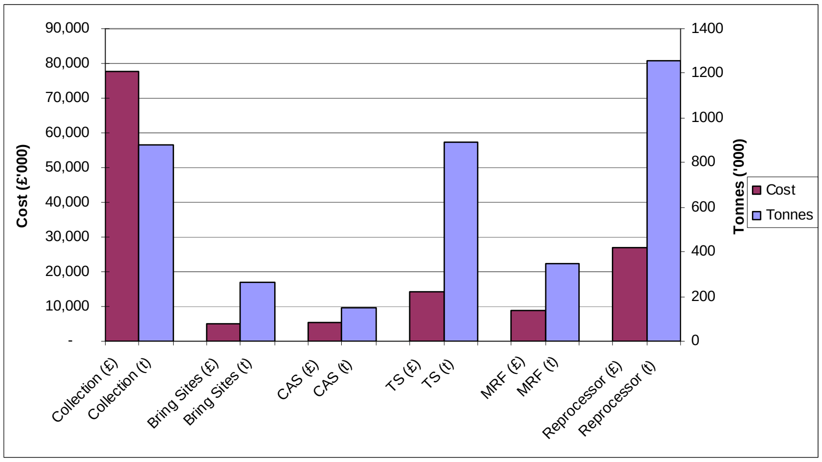

Figure 12: Total Cost and Tonnes Processed at Each Stage in Paper and Card Recycling Supply Route Activities
Note: Costs include onward transport from each facility type

The components of cost in paper and card recycling supply route activities are illustrated in Figure 13 below. Labour costs are the most important at most stages, although fuel, plant and machinery, and other facility costs are also important at some stages.

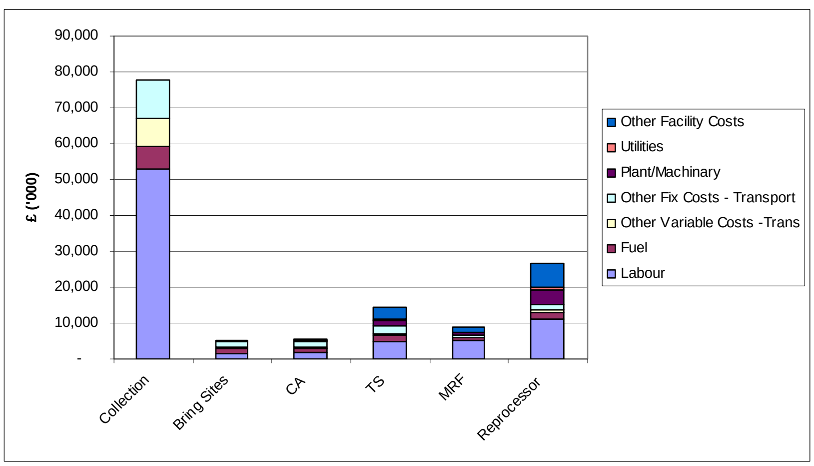

Figure 13: Components of Cost at Each Stage in Paper and Card Recycling Supply Route Activities
Note: Costs include onward transport from each facility type

3.3.2 Plastics

The costs and values for the key plastics recycling supply routes are shown in Figures 14 to 17 below. Again, the charts indicate two value stages in the chain. The first value arises where a price is paid by a plastics reprocessor to suppliers of waste materials (e.g. Local Authorities). The second value is the price paid by a plastics manufacturer to a reprocessor for reprocessed material. Prices for waste plastics are from October 2006, and are sourced from Letsrecycle.com. Reprocessed plastic prices are sourced from an industry expert.

In comparison to paper supply routes where the majority of costs tend to be early at the collection stage, for plastics, the main cost is in reprocessing.

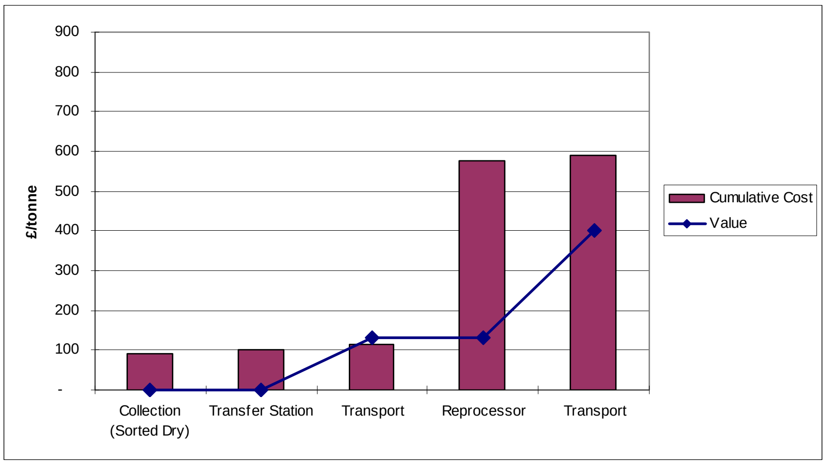

Figure 14: Cost v Value: Plastic from Sorted Household Collections

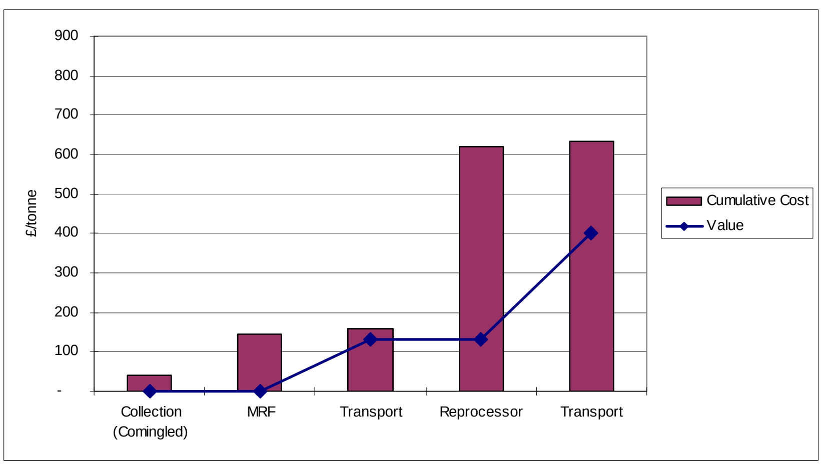

Figure 15: Cost v Value: Plastic from Co-mingled Household Collections

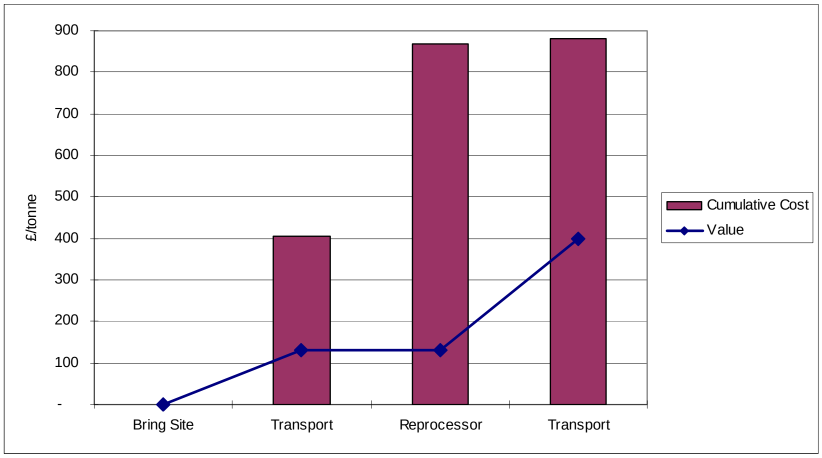

Figure 16: Cost v Value: Plastic from Bring Sites

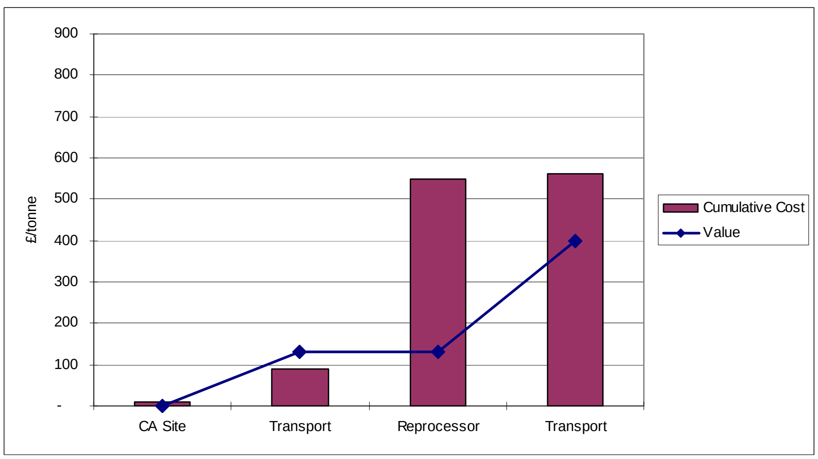

Figure 17: Cost v Value: Plastic from CA Sites

3.4 GREENHOUSE GAS EMISSIONS

A major driver of the project and the underpinning methodology was to better understand the economics of waste management supply chains: when represented in reality as a network of interlinked organisations. Primarily, the simulation was developed to consider financial costs. However, non-monetary costs and benefits (or externalities) should also be considered, as these are an important element in understanding the 'true' economics and drivers of waste management activities.

As the project aims to help inform policy decision-making, and environmental and social impacts (e.g. air pollution, noise, accidents) are key drivers in waste policy, it is imperative that both financial and non-financial costs and benefits are considered together. Understanding trade-offs is not always easy, since different units are involved, e.g. £s v emissions. Much research has been undertaken to understand environmental costs in monetary terms and is used by Government, e.g. sensitive lorry miles. We have not attempted to monetise environmental or social impacts of different systems at this stage, as this was not a part of the project, however, it would be entirely feasible to simulate these costs to investigate the wider costs of various systems.

We have considered emissions in terms of CO_2 equivalents. Estimated emissions from waste facilities are based on emissions factors published in a study undertaken for DEFRA[1]. Estimated transport emissions are based on DEFRA published emissions factors[2].

Table 14 shows the estimated net CO_2 equivalent emissions from facilities and transport. Reprocessing activities have net emissions benefits because the emissions savings from replacing virgin materials is taken into account. Overall, it is estimated that the net emissions from waste facilities processing household waste in England is 180,000 tonnes of CO_2 equivalent. Emissions from landfill contribute over 2m tonnes of CO_2 equivalent. However, reprocessing of materials has a net benefit of just less than 2m tonnes in saved emissions (this excludes 'other' materials).

Emissions from transport of household waste are estimated at nearly 188,000 tonnes of CO_2 equivalent. In this project because of the difficulties in attributing and allocating private journeys to move of waste to Bring and CA sites, emissions from these sources have not been included in the overall analysis. However, based on an average 5 mile round trip to CA Sites, it is estimated that car journeys contribute approximately 133,000 tonnes of CO_2 equivalent.

[1] ERM (2006) Impact of Energy from Waste and Recycling Policy on UK Greenhouse Gas Emissions
[2] DEFRA (2005) Guidelines for Company Reporting on Greenhouse Gas Emissions: Annex 1 - Fuel Conversion Factors

Process/Transport Activities	'000 Tonnes CO_2 Equivalent	Average CO2 Kg Equiv. Per Tonne processed/ transported
Transfer Station	23	2.4
MRF	9	16.8
CA Site	13	2.4
Composting	17	12.7
Landfill	2,047	113.0
EfW [(a)]	37	16.6
Total Net Emissions from Waste Facilities	**2146**	
Reprocessing and subsequent recycling [(b)]		
Aluminium cans	(166)	(11,634)
Glass	(322)	(556)
Paper/card	(741)	(496)
Plastic	(93)	(2,324)
Scrap metal	(181)	(434)
Steel cans	(26)	(434)
Textiles	(436)	(7,869)
Total Net Emissions from Reprocessing/Recycling	**(1965)**	
Household Collection	89	4.9
Transport from Transfer Station	26	2.6
Transport from MRF	4	7.7
Collection from Bring Site	17	24.7
Transport from CA Sites	30	5.5
Transport from Reprocessing 1 [(c)]	5	8.4
Transport from Reprocessing 2 [(c)]	13	6.6
Transport from Composting Facility	3	3.1
Transport from EfW	1	1.9
Total Emissions from Transport	**188**	
Total Net Emissions from Household Waste Management and Recycling	**369**	

Table 14: Estimated Net CO_2 Equivalent Emissions from Household Waste Management

Notes: [(a)] Net of offset from electricity generation. [(b)] Net of CO_2 benefits from displacing use of virgin materials. Bracketed figures indicate net CO_2 benefit. Includes all material delivered to the UK and Export markets. [(c)] Excludes emissions from transport to export markets.

Bring Site and CA Site car trips have been excluded, because of the uncertainty surrounding the primary purpose of these trips.

Bring Site servicing is considered to contribute little in terms of emissions and has been excluded.

Excludes net emissions from recycling of 'other' materials

Figure 18 below brings together the financial costs and greenhouse gas emissions resulting from various method of collecting paper from households and delivering to reprocessors. Sorted household collection is the most expensive method. CA Sites are the cheapest but the worst in terms of emissions. Bring Sites cost slightly more but have the least impact in terms of emissions. It should be noted that these results may not reflect upon the most desirable options for other types of recyclables.

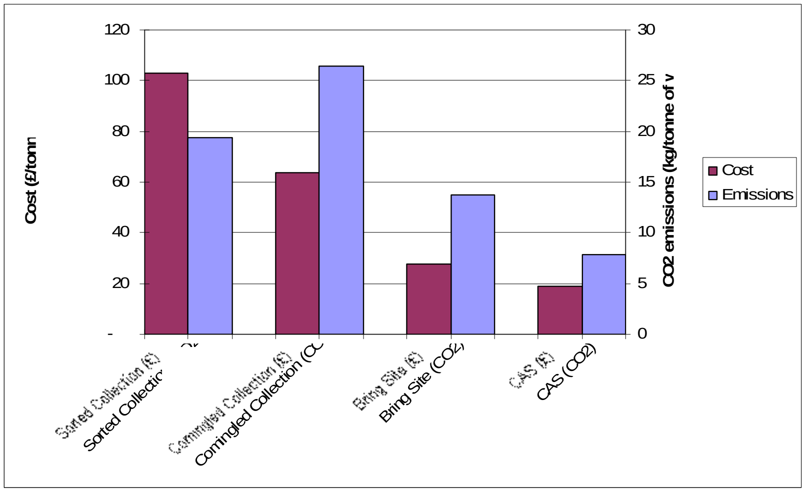

Figure 18: Recovered Paper: Comparative Cumulative CO_2 Equivalent Emissions and Cost per Tonne from Household to Reprocessor

Note: Excludes emissions from private car trips to Bring and CA sites.

3.5 TRANSPORT DISTANCES

In much the same way as ‘food miles’ is now an important issue in the environmental debate, the transport of waste or ‘waste miles’ has also received growing attention, particularly due to the increasing levels of exported waste. As yet, transport to export markets has not been assessed, although this would be entirely possible. However, detailed information on inland transport of household waste has been gathered.

Table 15 shows the estimated transport distances resulting from the collection and subsequent transport from each waste facility type. A total of 155.5 million miles per annum is estimated to have been covered in transporting household waste. Household collection is responsible for an estimated 72.7 million miles or just below 47% of all distance travelled.

Once again for consistency, this estimate excludes private car trips to Bring and CA sites, because of the uncertainty surrounding the purpose of those journeys. However, it is estimated that car trips to CA sites based on an average 5 mile round trip may amount to 460 million miles, considerably more than all the truck miles in the rest of the waste supply network.

Transport From:	Total Distance ('000 miles)	% of Total Distance
Household Collection	72,702	46.7%
Transfer Station	16,746	10.8%
MRF	2,701	1.7%
Bring Site	14,906	9.6%
CA Sites	34,551	22.2%
Reprocessing	11,862	7.6%
Composting Facility	1,692	1.1%
EfW	374	0.2%
Total	**155,535**	

Table 15: Total Distance Travelled in the Transport of Household Waste

Separate residual waste collections account for approximately 54 million miles or 74% of total household collection miles as shown in Table 16 below. Separate sorted dry recyclables collections are responsible for an estimated 12.5 million miles.

	Distance ('000 miles)	% of Total Distance
Residual Waste Separate	54,000	74.3%
Integrated Co-mingled	1,800	2.5%
Integrated Sorted	1,100	1.5%
Integrated Compost	169	0.2%
Co-mingled Separate	1,736	2.4%
Sorted Dry Separate	12,500	17.2%
Compost Separate	1,300	1.8%
Scrap Metal Separate	97	0.1%
Total	**72,702**	

Table 16: Transport Distance by Household Collection Method

Table 17 illustrates the estimated supply chain transport distances post household collection by waste material type.

More detailed data on transport of materials after household collection from each facility type is presented at Annex D.

Material	Total Distance ('000 miles)
Aluminium cans	391
Card	3,212
Co-mingled	1,608
Glass	9,864
Green waste/ Compost	4,855
Mixed cans	561
Other	19,132
Paper	9,375
Paper & card	2,840
Plastic	2,337
Residual waste	21,948
Scrap metal	3,986
Steel cans	1,136
Textiles	1,588
Total	**82,833**

Table 17: Estimated Transport Distances Post Household Collection by Material Type

4.0 RELIABILITY AND DISCUSSION OF RESULTS

4.1 RELIABILITY

The reliability of results clearly depends upon input data and assumptions. We have no concerns regarding the supply channels and that area of complexity.

The input cost data has been based upon various published sources as presented in Annex F. This data has the normal limitations in accuracy of actual knowledge and the way in which these costs were calculated. We have set out our assumptions in detail in order that revisions are possible and the output can reflect the latest knowledge.

It is clear that there is no one cost for anything, even at a particular time; costs of fuel, energy, transport, and raw material all differ on contractual terms, quantity, quality and a host of other factors. Consequently, ranges of costs are an essential and intrinsic element of 'waste to value' analysis.

At the recycler stage this is particularly important. The type and quality of material presented is critical to its potential for subsequent use.

Because of this real variability, we attempted to establish within each variable a 'comfort zone'; within which all the participants would be theoretically happy that the range of costs was realistic. Understanding the shape of the curve within the cost range is clearly important and we have set down our assumptions in that regard.

4.2 DISCUSSION

Because of the number of variables involved in the analysis and their different permutations we have reported and limited this paper to the major results. There is the capability to respond to more detailed and specific aspects of the 230,040 route options should it be either prudent or necessary.

Commentary on specific results is included above.

To achieve the best revenue contribution from waste and for waste to be realistically regarded as a resource, it is necessary to match the supply of waste from Local Authorities (LAs) with the demands of domestic and export markets.

However, within the current 'waste to value' supply channels there are clearly disparate aims, objectives and isolated (sometimes dysfunctional) decisions.

Local Authorities (WCAs and WDAs) are concerned with tonnage targets imposed by the EU and Central Government. They are asked to achieve them within a given budget and in relation to other social services and purposes. Consequently political choices regarding waste management are made reflecting these 'local' trade-off decisions. It was clear during the course of the project that the relationship between WCAs and WDAs is politically constrained and this affects option development and progress.

Recyclers, on the other hand, are concerned with value arising from specific grades or types of material and its quantity, quality, availability and presentation and they have their choice from C&I waste or household waste. To some extent this is reflected in the fact that most UK paper mills find MRF waste largely unacceptable for quality reasons.

Paper is a major contributor to target achievement in tonnage terms. The 50% of waste paper currently exported for recycling is helping to meet various targets. However, this is a risk to target achievement should export demand decline in the future. For some materials, e.g. plastics, increasing exports are restricting developments in UK recycling capacity.

Linking LA collection and material supply with recycler demand are the many and various routes identified at Annex E and for example at Section 4.1.4 above. The difference in material costs demonstrated by the high cost/low cost routes for specific materials evidences the limitation in assuming a single material route from 'waste to value'. It is equally erroneous to consider that any part of the 'chain' can be considered in isolation and treated accordingly. This interlocked nature of the flows means the alteration of certain activities can generate more change in system behaviour than others and overall system performance is dependent upon balance achieved amongst activities.

The cost of household collection generally dictates overall costs and is particularly sensitive to:

- Mix of materials, whether separate or co-mingled, since this 'consignment density' dictates whether the vehicle will first become full by weight or volume
- Size of vehicle, load density and level of compaction achieved
- Collection method

Collecting sorted materials is the most costly collection method because of the need for manual kerbside sorting and the additional time that this requires. Co-mingled collection is significantly cheaper for WCAs and is becoming increasingly popular. However, waste collected in this way requires further processing in MRFs and does not always provide the necessary quality of material needed by recyclers in certain material streams. Thus, while local authority tonnage targets are improved at less cost, the method adopted is not providing appropriate material quality to achieve its real resource value.

Additionally, it is reported that the move towards kerbside collection, and particularly co-mingled collections, has meant less material is taken to Bring Sites where it is usually separated. In some instances, for glass this has meant increased quantities of mixed glass and reduced quantities of colour separated glass from Bring sites.

There are 376 WCAs with almost as many different methods of collecting waste. There are 34 county councils and other unitary authorities that are WDAs. This fragmented management and infrastructure with political boundaries significantly limits any potential to be derived from economies of scale and the critical mass of material to make rail or other alternative transport modes more feasible than currently undertaken.

‘Waste miles’ are estimated to be 155 million miles or 3.8 billion tonne-kms. This mileage represents 38% of overall costs and results in 13% of total system carbon emissions (after deducting offsets for virgin material avoidance). The analysis shows that because of its overall importance and potential for cost and environmental savings, alternative transport modes and alternative transport fuels offer the possibility of significant reductions in financial and environmental costs.

While we were unable to measure and include all the variables concerning facility and transport emissions within the simulation, it was clear that the most financially cost efficient methods of moving waste to value were not necessarily the most environmentally sound. For example, the CO_2 cost per tonne of delivering waste to CA sites was 5 times greater than the CO_2 cost of kerbside collection (a situation not improved by the proposed method of collecting WEEE). This suggests that rather than use a monetary measure (i.e. ‘£s’) it would be useful to recalibrate our model with a metric based on emission variables in order to compare the comparative implications or even develop a £/ CO_2 measure.

5.0 MAIN IMPLICATIONS OF FINDINGS

As mentioned earlier, the interlinking and interacting nature of the processes and activities comprising waste collection, disposal and end use are very important. We therefore reiterate some of the points we made earlier within the context notes in the introduction (Section 1.2.3):

- There is a multiplicity of potential logistic paths (process nodes and links) available which are often based upon very local rationales for their selection; each pathway has their own specific characteristics and costs from origin to the ‘end’ market.
- The term ‘*supply chain*’ is actually misleading; the reality being a network of links, enterprises and organisation employing combinations of integrated facilities within various ‘*supply chain*’ architectures (combinations of nodes and links).
- Apart from reprocessors, the location of other facilities and their processes are not solely based upon a particular material type. Any change to the input mix or the quantity of a single material type will inevitably affect overall costs in general and other individual materials in particular.
- This has very significant implications for the analysis, because at any stage in the supply network, changes to the quantity and quality of one material will affect the cost of other flows in the network.

Our analysis reinforces the need for the ‘waste to value’ question to be reviewed holistically, i.e. between materials and facilities and the dynamics of cost, both financially and environmentally. Anything less and for the reasons that we have set down is largely reductionist and inevitably compromises policy analysis.

Waste, mixed and separated, flows through an integrated network and this is an holistic problem that has to be analysed holistically in order that identified dysfunctional elements can be reviewed appropriately and realistically within a hierarchy of importance. This project’s approach demonstrates that the most data sensitive factors can be identified to enable and extend the range of situations and problems that can be analysed within the overall context. Essentially providing the ability to progressively refine the understanding of various policy instruments and manage the overall problem while allowing stakeholders to manage their budgets and environmental impact effectively.

The project indicates and suggests that 'tonnage' based targets on local authorities has led to a proliferation of methods and infrastructure requirements producing a supply of material that is not always of acceptable or appropriate quality for use in the domestic market. While the export market currently consumes significant quantities of collected material and is willing to accept poor quality materials from the UK market this has potential risk because:

- It is not solely within UK control
- The quantity of waste collected for recycling is increasing
- The quantity of material to landfill is decreasing
- The UK recycling capacity is declining in some materials, e.g. paper mill closures
- The cost of UK reprocessing is increasing, e.g. energy and transport prices
- UK waste exported is effectively providing subsidised raw materials for overseas manufacturers
- There is a long lead time in developing UK waste infrastructure

It is unrealistic to consider disposal methods, recyclable materials and export markets without due concern to these tactical and organisational issues.

From our observations, research and analysis we can suggest a number of reasons why there are opportunities to improve the efficiency of the current 'waste to value' system:

- The often competing aims and objectives between WCAs, WDAs, Central Government and commercial organisations leads to confusion, which drives complexity and cost.
- Varying levels of commercial involvement. Our observation is that most Local Authority services are outsourced which has led to some marked differences in the cost of services from place to place and different attitudes to the role of contract management.
- The fragmented structure of organisation and administration. For a country as small as the UK, the idea that an efficient logistic service can be provided by over 500 different organisations all with their own political and personal ideas and interpretations is limiting in supply chain terms. Based upon logistics process re-design in a country of the UK's size, consideration should be given to establishing one central waste authority that could more effectively:
    - Reduce duplication, complexity and costs
    - Provide an holistic approach to decision-making in both financial and environmental issues
    - Gain economies of scale
    - Organise and facilitate the use of alternative modes of transport more effectively
    - Work with the waste management industry and recyclers to optimize resource use and value
    - Enable waste management contracts to be negotiated from a stronger 'intelligent customer' position

- The current knowledge, rate of change in costs and the essential dynamics of waste management mean that any contract over a period greater than 3 years has inherent risk and is opportunistic. The current length of PFI contracts, some as long as 25 years is unlikely to be effective since it is impossible to conjecture upon the situation that might exist that far in the future. Also their cost must necessarily reflect the considerable commercial risks involved.

Overall, the results demonstrate the complexity of the 'waste the value' structure and the unnecessary difficulties (costs) that this imposes on its management and decision-making.

We believe that there are significant benefits to be gained from:

- Balancing the target driven supply push and domestic demand pull, in terms of quantity and quality.
- Producing economies of scale and the critical mass of material that would be possible to make rail, inland waterways and offshore shipping more valid options, and possibly alternative fuels, e.g. biofuels, natural gas. For example, one train load is the equivalent to at least 40-50 truck loads and therefore offers significant environmental, and potentially, financial benefits.
- Strategically locating facilities (based on UK demographics) to provide a service to the most people and ensuring the adequacy of feedstock at the least transport cost, irrespective of political boundaries, and possibly reducing the number of facilities needed.
- Harmonise activities throughout the supply chain to ensure balance between them.
- Taking a wider, more integrated strategic approach to reduce waste management complexity.

6.0 POSSIBLE FUTURE WORK

The underlying research and design analysis necessary to develop the 'supply chain' business model together with the outputs of the time-based simulation suggests fruitful areas of possible future research should include:

- Update the current analysis with data from 2005/06 (already underway) and include forecast factors (seasonalities and annual growth) to explore future trends and sensitivities.
- Further develop the analysis of environmental and social non-monetary costs and benefits. It would be possible to place monetary values on externalities e.g. emissions, to investigate and compare 'true' costs of different system and technological options.
- Re-calibrate the model to explore policy 'levers' at national, regional or local levels and 'what if' scenarios e.g. Regulatory Impact Assessment, PRN's, carbon taxes, PAYT. Best undertaken in liaison with and incorporating other policy analyses.
- Examine the potential from economies of scale, alternative technologies and transport modes
- Examine the selective elimination of LA boundaries and the potential for cost reductions.

- Examine the Business options of pay as you throw (PAYT) or "paid to throw" systems.
- At macro-economic level, examine the structure of control, investment rate of return and full 'market' behaviour from a commercially operated public sector waste system. Such a re-design would enable the impact of 'commercial' best practices and incorporate legislation to be analysed within the model to explore the best overall combination.
- Investigate the transport implications of exported recyclables, i.e. costs, distance and emissions.
- Explore the potential costs and impact of including and managing household waste with C&I waste.
- Consider investigating supply chain economics for a smaller geographical area e.g. a county where it should be possible to obtain more detailed data, and therefore understand more clearly and compare the costs and benefits of operational activities and decisions.
- Development of the business modelling/simulation technique to enable local authorities to become 'intelligent customers' in the procurement of waste management services and contract evaluation. Provide a consistent approach to base case costing and 'public sector comparators'.