Developing Life Cycle Inventories for Waste Management

CWM 128/97

Developing Life Cycle Inventories for Waste Management
Report No. CWM 128/97

Volume No. 1 of 2

PLEASE NOTE

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Developing Life Cycle Inventories for Waste Management

Volume No 1 of 2

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Foreword

There is increasing pressure on waste managers and waste regulators to deliver a sustainable approach to waste management.

Although there have been frequent claims of the superiority of certain options, waste management decision making has seldom, if ever, involved a thorough assessment of environmental costs and benefits. Yet, if we are to achieve sustainable waste management, we must develop integrated strategies that result in the least overall harm to the environment. Thus there is a need for an aid to objective and consistent decision making that has the confidence of industry, regulators and the public. Life Cycle Assessment has the potential to meet this need.

This report covers the first phase of the Department of the Environment's programme to extend the application of life cycle techniques to waste management[1]. It deals mainly with the development of guidelines for the compilation of life cycle inventories for waste management options and represents the first step in the development of a tool for the better evaluation of waste management options at national and local level.

It is not, however, a universal solution. Cautious interpretation of the results of Life Cycle Assessment studies can guide these choices but cannot make them. The importance of obtaining accurate and relevant data cannot be stressed too highly but, even so, the outcome of a Life Cycle Assessment is likely to be subject to uncertain estimates of incommensurable environmental effects. In the end, as Funtowicz and Ravetz (1990), concluded:

"Managing our technologies must be based on coping with ignorance at least as much as on the application of knowledge".

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1 The programme is currently run under the auspices of the Environment Agency following the transfer of Wastes Technical Division from the Department to the Agency in April 1996.

Executive Summary

1. This project is the first part of the Department of the Environment's Life Cycle Research Programme for Waste Management, which seeks to apply the techniques of Life Cycle Assessment (LCA) to the treatment, management and disposal of controlled wastes[1].

2. LCA is a methodology used to quantify the environmental burdens (resources used and associated releases to air, water and land) for a given product or process, and to assess the effects that these burdens have on the environment.

3. The purpose of this report is to develop a framework for applying Life Cycle Inventory Analysis (LCI), the first stage in conducting a full LCA, to options for the management of non-hazardous wastes. LCI defines the system to be studied and compiles the resources used and wastes and emissions generated in the form of an Inventory Table.

4. In Volume 1 of this report the key concepts underlying LCA are introduced and the component parts of LCI are considered in relation to the management of non-hazardous wastes.

5. This application of LCI leads to the identification of environmental burdens associated with waste management activities themselves and burdens arising from demands made by waste management activities on other parts of the economic system, for example, the consumption of grid electricity. Avoided burdens may also be identified. These are 'credits' to the system because of flows from waste management activities to the remainder of the system. For example, electricity generated from waste incineration displaces electricity from existing power stations and avoids associated environmental burdens.

6. On the basis of this discussion, a set of guidelines has been developed which establishes general principles for applying LCI to waste management and which makes recommendations on how to address specific problems in this field.

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7. To facilitate the process of Inventory Analysis, a twin-track system has been developed, capable of describing any waste management option as a combination of generic unit operations and the characteristics of the waste undergoing the unit operations. The main benefit of this approach is that it can describe different waste management activities in a consistent manner and with a high degree of resolution. Because the unit operations are defined separately from the wastes handled, the approach is also suited to identifying separately the effects of waste flow and waste composition on the burdens arising from any waste management options.

8. Supporting material giving more detailed background information about current waste management practices and LCA methodology is provided in Annexes (Volume 2) to the main report.

Introduction 1

This Report and Life Cycle Assessment

1.1 Life Cycle Assessment (LCA) is the compilation of the inputs and outputs associated with a product or process throughout its entire life, from the extraction of raw materials required to eventual disposal, and the evaluation of the environmental impacts associated with these inputs and outputs.

1.2 The process of LCA is generally divided into four stages: goal definition and scoping; inventory analysis; impact assessment; and interpretation, each of which are explained in general terms in Chapter 2 of this volume, and in more detail in Annex 2 of Volume 2. However, the primary focus of this report is the first two stages of LCA. It therefore deals principally with the issues relating to goal definition and scoping and to the compilation of the inventory, and makes detailed recommendations in order to develop guidelines for carrying out a Life Cycle Inventory Analysis (LCI) for the management of non-hazardous controlled wastes, and particularly the components of household waste.

The DoE LCA Programme

1.3 The Department of the Environment's life cycle research programme for waste management seeks to apply the techniques of LCA to the treatment, management and disposal of controlled wastes[1].

1.4 The overall aim of the programme is to provide an objective basis for comparing the different options for the management of all controlled wastes by developing a methodology to allow decisions to be made on a consistent basis. The output from the programme should assist those concerned with developing practical policies for waste management and place the assessment of the environmental costs and benefits of various options on a much sounder footing.

1.5 The programme is being carried out in the following phases:
Phase 1 - methodological guidelines for inventory analysis;

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1 The programme is currently run under the auspices of the Environment Agency following the transfer of Wastes Technical Division from the Department to the Agency in April 1996.

Phase 2 - impact assessment and damage cost valuation;
Phase 3 - data gathering and inventory analysis;
Phase 4 - model development; and,
Phase 5 - decision tool applications.

This Project

1.6 This report covers the first phase of the Department of the Environment's life cycle research programme for waste management: the development of guidelines for carrying out LCI[2], and has the following main objectives:

- to develop a framework for the LCI of options for the management of non-hazardous controlled wastes, with special reference to the components of household waste; this framework is to be in the form of a set of guidelines for subsequent work; and,
- to produce skeleton inventory tables for an LCI of the waste management options for non-hazardous controlled wastes and the components of household waste.

1.7 In particular the methodology was required to:

- discuss the determination of the system boundaries of the relevant waste management options to be studied (focusing on household wastes and other components of Municipal Solid Waste (MSW));
- discuss the unit on which analysis and comparisons are to be based (the so-called functional unit, see Chapter 3);
- describe the transport and operational processes potentially taking place within the system boundaries;
- identify (but not at this stage quantify) the environmental burdens which may arise at specific points within each process; and,
- define the methodological guidelines required to apply LCI to a given waste management option and for subsequent work.

1.8 In addition, a consultative workshop was held to discuss this work and inform this report.

1.9 This phase of the programme concentrated on non-hazardous controlled wastes with particular emphasis on household wastes, for the simple reason that more knowledge exists about this than any other generic waste type.

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2 LCI is the part of LCA which deals with the compilation of the inputs and outputs associated with a product or process throughout its entire life cycle (see Chapter 2).

1.10 The report is arranged in two volumes. Volume 1 is the main report and Volume 2 contains a number of Annexes providing more detailed supporting information.

Volume 1

Chapter 1 **Introduction**

Chapter 2 **Life Cycle Assessment**
An introduction and explanation of key concepts about LCA and LCI for waste management specialists.

Chapter 3 **Goal Definition and Scoping for Waste Management**
This considers the first stage of LCI as applied to waste management activities. Outstanding critical issues are highlighted.

Chapter 4 **Inventory Analysis for Waste Management**
Following the definition of Goal and Scope, this Chapter addresses the compilation of inventories of environmental burdens.

Chapter 5 **The Description of Waste Management Activities**
This describes a method of standardising the description of waste management activities using generic unit operations and waste characteristics.

Chapter 6 **The Identification and Characterisation of Environmental Burdens**
Provides detailed guidance on how to identify and quantify the environmental burdens which need to be included in the Inventory.

Chapter 7 **Guidelines for Compiling Life Cycle Inventories for Waste Management**
The recommended guidelines for comprising Life Cycle Inventories for waste management are summarised.

Chapter 8 **Illustrative Example**
The recommended guidelines for compiling a life cycle inventory for waste management are illustrated by working through an illustrative case study.

Chapter 9 **Conclusions**

Volume 2

Annex 1 **Overview of Waste Management**
A broad-brush introduction to typical waste management options for the benefit of the non-specialist.

Annex 2 **Overview of Life Cycle Assessment**
A more detailed explanation of the key concepts and current state of development of LCA.

Annex 3 **Product and Process Related Burdens**
A discussion of the critical issues involved in considering how waste composition can affect environmental burdens.

The Audience

1.11 Although the results of the programme should be of value to all those concerned with waste management, its outputs are principally aimed at informing two areas of policy:

i) national waste management policies and, in particular, the waste strategy for England and Wales; and,
ii) waste management planning at the level of development planning and regional planning conferences.

1.12 The guidelines within this report should be used by those consultants who may be involved in subsequent phases of the programme to ensure the consistency necessary in the collection of inventory data and the development of inventories for the different waste management options. It should also be of interest to all those involved in the waste management industry and to the LCA community for its consideration of the methodological aspects of applying LCA techniques to waste management practices.

The Background to this Study

1.13 As the environmental management of different waste management options has improved, so the focus of public debate has switched from the standards of particular sites to more general and fundamental questions concerning the options available for the management of waste and the issue of sustainability. The principles of sustainable development demand that the current production and disposal of waste materials should not limit the range and quality of resources which will be available to future generations. The environmental policies of the European Commission and the UK Government emphasise the importance of developing a sustainable approach to waste management, and recognise the resource potential that wastes possess, both in terms of their materials and energy contents. Thus there is a strong policy presumption that wherever possible these resources will be recovered.

1.14 European waste strategy and legislation already embodies a preferential order for waste management options, (The Framework Directive on Waste 75/442/EEC as modified by 91/156/EEC), arranging these in a hierarchy. This waste hierarchy has been developed and included in Making Waste Work: A strategy for sustainable waste management in England and Wales' (Department of Environment, 1995).

Reduction Reducing the production of waste to the minimum consistent with economic sustainability.

Re-use Putting objects back into use. For example, reusing bottles.

Recovery Finding beneficial uses for waste, including:

i) **Materials Recycling**. Putting materials back into use, e.g., reusing the glass from bottles;
ii) **Composting**. Processing organic waste to produce a soil improver or growing medium; and,
iii) **Energy Recovery**. Burning waste and recovering the energy, or collecting and using landfill gas.

Disposal The least attractive option because no benefit is obtained from the materials.

1.15 The hierarchy apart, the current array of EU and UK legislation governing waste management practice has arisen more as a result of *ad hoc* responses to specific problems than from any truly integrated waste management philosophy. Even the waste hierarchy itself, which purports to show options in order to their relative effects on the environment, is based on assumptions about effects that are neither clear nor universal. If the principles of sustainable development are to feed through into environmental policies on waste, options for waste management need to be considered in the context of a wider strategy for the management of material and energy resources.

1.16 'Making Waste Work' represents the first concerted attempt by the Department of the Environment to adopt an integrated approach to waste management policy. However, in setting aspirational targets that seek to change the proportions of various waste streams dealt with in a particular way, it inevitably raises questions about the scientific basis of the targets and whether sufficient information is available to make proper judgements about which management option is the least damaging to the environment for each type of waste. One such target is that of recycling half the recyclable content of household waste (estimated at 25% of total household waste). While this has undoubtedly been the principal driving force in increasing the amount of recycling carried out by local authorities, few, if any, have given consideration as to whether this results in an overall benefit to the environment and the economy.

1.17 At a more practical level, waste management planners are required to assess the options for dealing with waste and to recommend the best overall policies. The waste management industry is submitting applications for new facilities and development planners are taking decisions on the basis of what is often inadequate and inconsistent information. There is a growing recognition of the need both to establish the environmental effects of different options and to provide a common basis for decision making in waste management.

Non-Hazardous Waste Arisings

1.18 This methodology addresses the management of all non-hazardous Controlled Wastes[3], with emphasis on the components of household waste. Waste management includes the collection, transportation, separation, treatment and ultimate disposal of wastes and any residues.

1.19 It is estimated that about 210 million tonnes of Controlled Waste are generated in the UK per annum (Figure 1.1, Table 1.1). The non-hazardous element of Controlled Waste is generated from a variety of sources, principally:

Household — Mixed household refuse placed in dustbins and plastic sacks for doorstep collection and larger items and garden waste taken by householders to Civic Amenity sites. Also separated materials, paper glass etc., taken to recycling banks;

3 Controlled Wastes include those arisings from household, commercial or industrial premises, but exclude agricultural wastes, mining and quarrying wastes, dredging spoils and sewage sludge spread on land or at sea.

Figure 1.1: Annual UK Total Waste Arisings (Millions of Tonnes Per Annum)

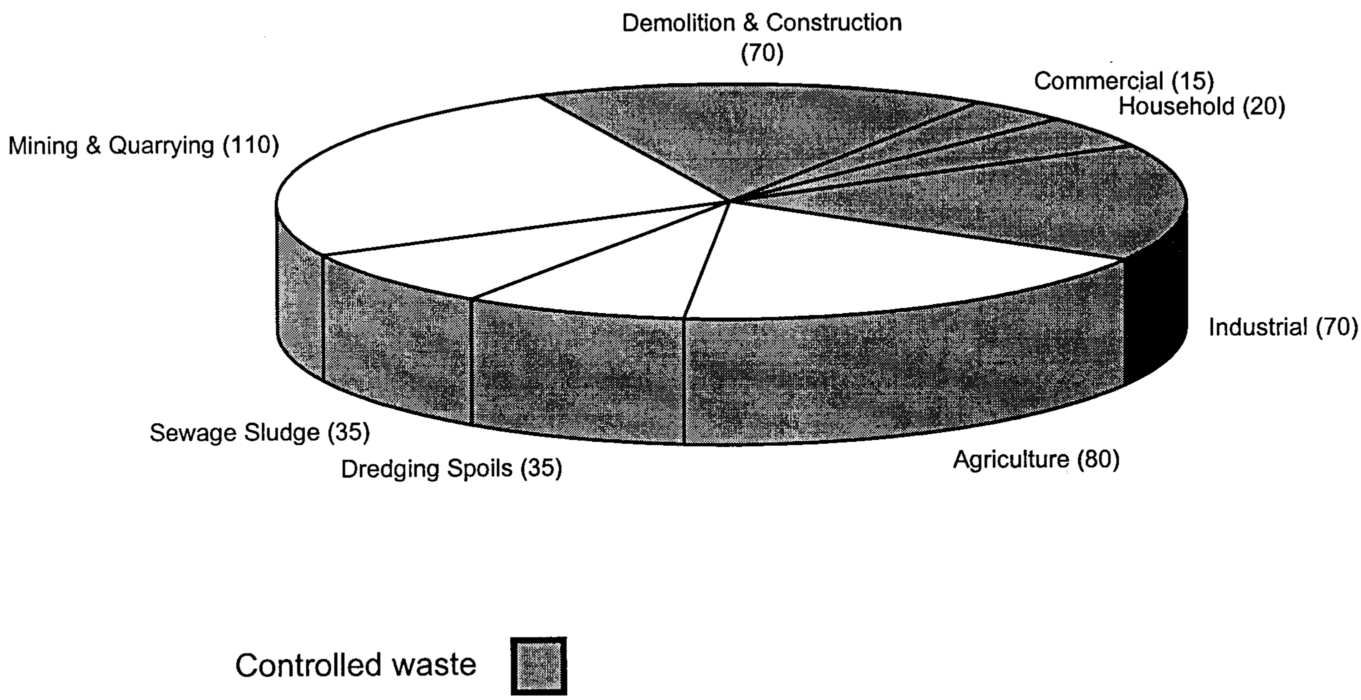


Table 1.1: Estimated Annual UK Controlled Waste Arisings

Category of Controlled Waste	Total Arisings (millions of tonnes per annum)	Percentage of Total Controlled Waste Arisings
Household	20	9
Commercial	15	8
Industrial	70	33
Construction & Demolition	70	33
Sewage sludge[1]	35	17
TOTAL	210	100

Source: Department of the Environment

1 Sewage sludge is only a controlled waste when landfilled or incinerated

Commercial	General refuse from offices, restaurants, shops etc. Mainly dominated by paper and card, but may contain a proportion of putrescible material;
Industrial	Waste from industrial processes. May involve very large quantities of single materials, for example, blast and steel furnace slags, food and processing wastes, etc.; and,
Demolition and Construction	A high proportion of concrete and brick, but also including soil, stones and asphalt and smaller amounts of wood, plastic, metals and insulation materials.

1.20 The term Municipal Solid Waste (MSW) is commonly used to describe collectively all the non-hazardous wastes collected by local authorities (or their contractors). This includes wastes collected from households and from some (but not all) commercial and still fewer industrial premises, together with wastes delivered to Civic Amenity (CA) sites by householders. In practice it is MSW that is the *de facto* waste stream with which this phase of the project is primarily concerned.

Life Cycle Assessment 2

What is Life Cycle Assessment?[1]

2.1 In the latest ISO standard, LCA is defined as a technique for assessing the environmental aspects and potential impacts associated with a product or service system, by:

- compiling an inventory of relevant inputs and outputs of a system;
- evaluating the potential environmental impacts associated with those inputs and outputs; and,
- interpreting the results of the inventory and impact phases in relation to the objectives of the study.

LCA studies the environmental aspects and potential impacts along the full length of the product or service systems life. From the production of primary raw materials to their use and disposal.

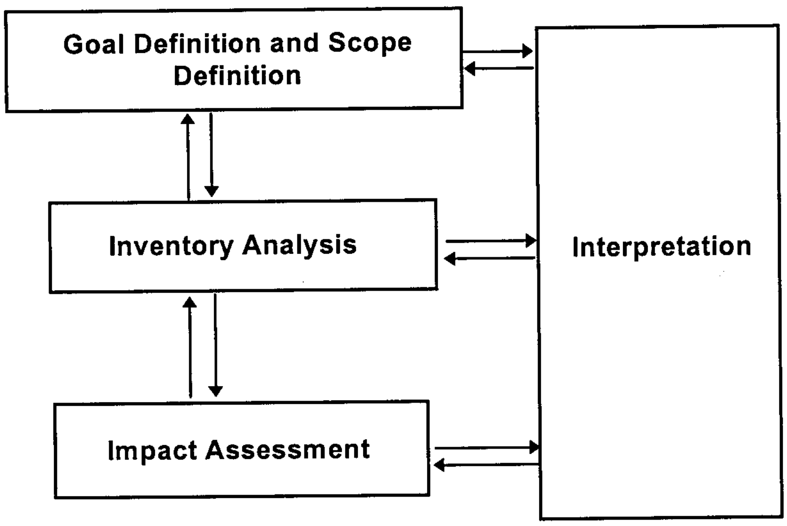
2.2 Life Cycle Assessment is a means of quantifying the resources used, as well as the associated releases to air, water and land (environmental burdens) for a given product or service system. The relevant material and energy flows are followed throughout the entire system life cycle from cradle, i.e. primary resources, to grave, i.e. release of emissions and residues to the system environment. For this reason, LCA is also sometimes known as 'cradle to grave analysis'. LCA further attempts to relate these quantified environmental burdens to their consequential effects upon environmental concerns, such as primary resource depletion and environmental damage (environmental impacts). The results of an LCA study should provide information which can be used to improve environmental performance.

1 Throughout this report the guidance given by the International Standards Organisation (ISO) on terminology has been followed and a glossary of terms and their meanings is given at the end of the report. 'Life Cycle Assessment' encompasses all four stages described in Paragraph 2.3. 'Life Cycle Inventory Analysis' is used to denote the process of compiling the inventory table and the data in the table itself are referred to as the 'Life Cycle Inventory'. Any study not including impact assessment is therefore a 'Life Cycle Inventory Analysis' study. The term 'Life Cycle Analysis' is avoided.

2.3 Life Cycle Assessment may be subdivided into four stages (Figure 2.1):

i) **Goal definition and scoping,** which defines the system to be studied and the functional unit on which the study is to be based;
ii) **Inventory Analysis,** which compiles data on resources used and wastes and emissions generated in the form of an inventory table;
iii) **Impact Assessment,** which converts the inventory table into an understandable evaluation of the magnitude and significance of the potential environmental impacts; and,
iv) **Interpretation**, where the inventory and impact assessment results are assessed in line with the goal and scope of the study.

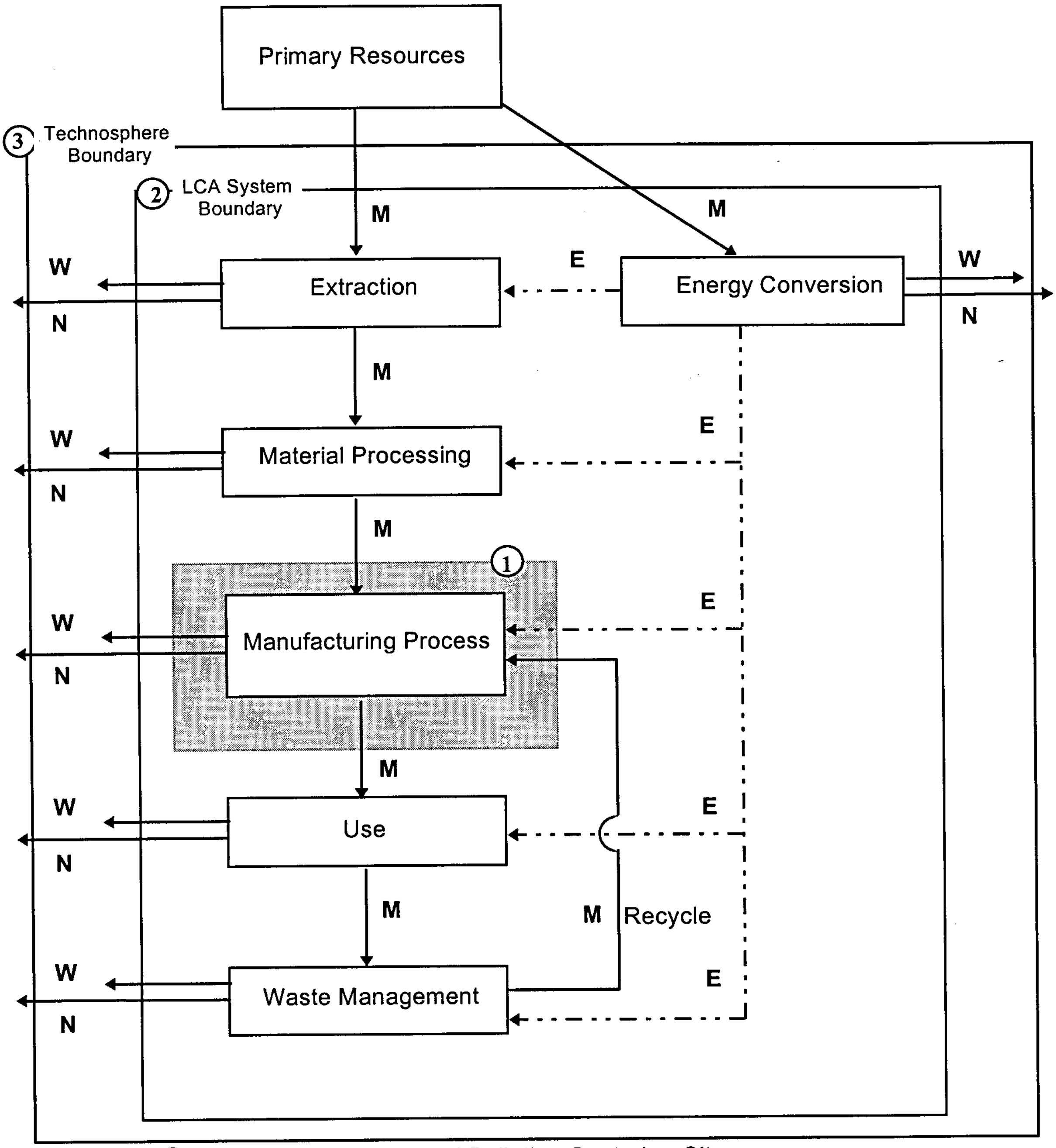
Figure 2.1: The Components of Life Cycle Assessment



2.4 In fact, the overall process should be iterative and at each stage, as the assessment proceeds, there is a need to revisit and update earlier stages. Goal Definition and Scoping, and Inventory Analysis are of primary concern in this report, and are therefore covered in more detail in Chapters 3 and 4 respectively.

2.5 However, to understand how LCA may assist in making practical decisions that are most beneficial (or least damaging) for the environment, some brief explanation of the terminology and the method is necessary. These terms are defined in the glossary. Figure 2.2 shows a schematic representation of LCA.

Figure 2.2: The 'Cradle to Grave' Nature of Life Cycle Assessment



1 Boundary of Integrated Pollution Control or Site Specific Environmental Impact Assessment

2 Boundary of LCA System

3 Boundary between human activities and the 'Natural' environment

M Material
E Energy
W Waste
N Elemental flows to nature

The System, The System Boundary and The Environment

2.6 LCA may be regarded as a form of environmental system analysis. The system represents everything to be taken into account in the study, i.e. the human economic activity which contributes to the functional outputs in the form of desired goods and services. It will necessarily include the activity under study (for the purposes of this programme waste management activities) but should also include upstream and downstream activities directly linked with the product or service under study (shown as extraction, material processing, manufacturing process etc.) and any other activity that is significantly affected by the activity that is the subject of the study.

2.7 The system boundary is the border drawn between the system under study and the environment. The environment is defined as it is in thermodynamics as anything outside the system boundary. A further boundary exists between the 'technosphere' which includes the full sphere of human activity, of which the system is a part, and the natural environment.

2.8 The way the boundary between system and environment is drawn, that is, what the assessment takes into account, is the essential feature that distinguishes LCA from other environmental management tools. This is shown schematically by Figure 2.2, which compares the life cycle system boundary with that for Integrated Pollution Control, which tends to concentrate on the manufacturing process.

2.9 LCA thus extends the system boundary back to primary resources, such as fossil fuels or ores in the ground, and downstream to waste disposal. It may also extend the boundary in time to take into account the slow release of materials or energy across the 'physical' system boundary. This distinction is central to the application of LCI to waste management developed in this report.

Flow Diagram

2.10 A flow diagram is a schematic representation of all the activities within the system which are therefore taken into account in compiling the inventory of environmental burdens. Flow diagrams are usually prepared at different levels, the most general showing the various stages of the life cycle within the system as boxes. Each of these boxes will be connected to one or more other activities by arrows that represent the material and energy that link these activities. In Figure 2.2 energy and material flows between each of the stages (and, if they occur, from the environment to the system) are shown by appropriate arrows.

2.11 **Unit operations** are defined as the smallest portion of a system or activity for which data are collected. Further flow diagrams may be prepared showing all the unit operations into which the activity under study and if necessary the associated activities may be subdivided.

Environmental Burdens and Environmental Impacts

2.12 Flows of matter and energy that cross the system boundary into or out of the natural environment are termed elemental flows or environmental burdens. These may therefore be either primary resources used, or emissions released by the various activities within the system. In Figure 2.2 the emissions from the system to the natural environment are shown as N and those to the technosphere shown as W. Each flow shown by an arrow marked 'W' will almost certainly consist of many individual flows, each of which should be identified on one or more flow diagrams (usually done at the more detailed level).

2.13 Each of the environmental burdens will have a specific effect on the environment, which will generally be related to the amount and 'concentration' of the matter or energy and the nature of the environment which it is affecting. The effects of the burdens on the environment are termed environmental impacts. Thus, for example the release of carbon dioxide (an environmental burden) will contribute to global warming (an environmental impact).

2.14 In analysing the results of an inventory it is sometimes useful to make distinctions between burdens, or elemental flows, coming from different areas within the system. Two areas are quite frequently defined:

1. the **foreground**, which comprises those operations directly under study which may be affected directly by the decisions based on the study. Burdens arising from this area are defined as **direct burdens**; and,

2. the **background**, which comprises operations receiving or supplying materials or energy from the foreground system which are presumed to be unaffected by the outcome of the study. Burdens arising from this area are defined as **indirect burdens**.

2.1.5 The assumption is made that, with the exception of the foreground system the inputs and outputs of the technosphere remain constant. Thus if a material or energy flow is imported from the technosphere this will cause an operation within the technosphere to step up production. These operations, if significant, are included within the system boundary in the background system.. Similarly if a useful material or energy flow is exported to the technosphere this will cause an operation within the technosphere to reduce production. If significant these avoided operations are also included within the system boundary. The burdens associated with these operations credit the system and are defined as **avoided burdens**.

Functional Unit

2.16 The activity that is the focus of the study will necessarily have a function. This function may be the provision of a product or a service. The most appropriate function will relate to the goal (i.e., objective) of the study and, at the scoping stage, this function needs to be expressed as a common unit of measure to which the environmental burdens can be related in the inventory. The burden NO_x may be identified in a unit operation as arising from the transport of a given quantity of bottom ash (from a MSW incinerator) which is the reference flow for that unit operation. In the eventual inventory the burden must be related to the functional unit of the system, e.g. unit of waste disposed. Similarly the quantity of every other burden in the inventory must also relate to this, the common functional unit.

The Inventory and its Compilation

2.17 The inventory (or inventory table) is effectively a totaled environmental balance sheet containing the burdens identified for each of the separate unit operations that are included within the system. It is typically produced in the form of a table or computer spreadsheet with the burdens on one axis and the processes on the other. The burdens for inclusion in the inventory table are derived (initially) from the detailed information collected on each unit operation. All material and energy flows are quantified in relation to the functional unit. Materials and energy balances should be carried out across each of the unit operations in the system in order to identify potential omissions and errors. The summation of the inventory across all processes is often referred to as the **inventory results**. In some instances the inventory results may be negative because of the inclusion of avoided processes. This indicates an overall reduction in emissions or resource use.

Sensitivity Studies

2.18 A sensitivity study is one carried out to establish how sensitive the result of an LCI is to variations in the particular values of data in the inventory. Such studies can be used to establish the reliance that may be placed on the result of the life cycle study; to demonstrate where improvements in environmental performance may be most effective; or to indicate the data for which more precision is required before the results of the study satisfy the goal initially defined.

Life Cycle Assessment and Other Environmental Management Tools

2.19 LCA is an environmental decision support tool that will aid, not make, decisions on the best environmental option of those under consideration. It should be used in conjunction with other environmental management mechanisms, such as risk assessment and environmental impact assessment, to assist in making decisions that affect the environment. The advantages that LCA offers over other methods of comparing different processes is that it should be comprehensive, consistent and transparent.

Life Cycle Assessment as a Policy Tool

2.20 Environmental policies and decisions tend to be made on the basis of solving 'one problem at a time', in the hope that a gradual improvement will be achieved. While this has tended to be true there have been some notable exceptions[2], and the complexity of waste and the wide range of practicable options now available for different parts of each waste stream, mean that such a compartmentalised approach to problem solving may not secure the degree of environmental improvement that is possible. Moreover, attempts to solve problems in isolation from the effects that the solutions themselves may have, could result in a change for the worse rather than for the better when the environment as a whole is considered.

Data Requirements

2.21 However good the guidelines, a decision support tool will only be as good as the information that is available to feed into it. Much of the subsequent work of this programme will necessarily revolve around the collection of data for

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2 In waste management, this has been particularly evident in the changes to landfill practice over the past 25 years, where efforts to provide a 'solution' to one problem have created another, for example, compacting and covering waste to reduce flies and vermin has resulted in increased anaerobic degradation and methane in landfill gas.

inventory analysis. The quality of data, and the confidence in which results can realistically be held, is a factor of crucial importance in life cycle assessment, as in other fields.

2.22 The outcome of an LCA may provide 'soft' or indicative information, but decisions on waste management strategies are 'hard' choices between distinct alternatives.

2.23 It is not justifiable to make decisions using average or best estimate data when the sources of error are known to be great and the stakes are high. The situation was put succinctly by Wilson, Crouch and Zeise (1985).

"A decision made without taking uncertainty into account is barely worth calling a decision."

Goal Definition and Scoping for Waste Management   3

Introduction

3.1 Chapter 2 outlined the technique of Life Cycle Assessment, and introduced the concept of using it as a tool for waste management. This Chapter considers the first stage of LCA, Goal Definition and Scoping, in the context of applying the methodology to the comparison of alternative waste management options. The methodology discussed closely follows the *Guidelines for Life Cycle Assessment : A Code of Practice* (SETAC, 1993), to which the reader should refer for further guidance in the general conduct of LCA studies. Two illustrative examples are used to indicate the application of the technique. In particular, methodological problems are highlighted and recommendations made as to how they may be overcome.

3.2 The Chapter is divided into two sections:

1. **Goal definition**, in which the overall objective of the study is linked to the choice of comparative scenarios; and,
2. **Scoping**, during which the study is planned, the functional unit set and the initial system boundaries are defined. In addition consideration is given at this stage to the burdens to be considered and to data quality goals.

Goal Definition

3.3 Defining clearly the goal, i.e. the purpose, of the study is vital to its success. The stated goal will determine the scope of the study, and will influence the way in which all the subsequent stages of the application are carried out. The goal will frequently be to guide decisions on choices between options; in the context of this report, waste management options. When carrying out an LCI, scenarios are usually developed which describe or model the option(s) being addressed. Care must be exercised in the choice of scenarios to ensure that they are appropriate to realising the goal of the study. For most applications the first and most obvious scenario is 'current practice'. Other scenarios may be based on proposed practical alternatives, or may be theoretical scenarios also relevant to the goal of the study.

The choice of other scenarios to be considered in a study evaluating improvements or changes will depend on such factors as:

- the time-scale over which any prospective change is to be made;
- the resources available for making the change; and,
- local conditions, e.g. the availability of suitable sites (local/regional applications).

The iterative nature of the LCA process requires the choice of scenarios to be continually reviewed and tested against the goal to ensure that the latter will be met.

3.4 The goals and associated scenarios for the two illustrative examples are described below:

GOAL DEFINITION AND SCENARIO SETTING	
Example 1 Central government intend to commission a study to be used to inform policy decisions. Specifically the concern of the government is to inform the choice of options for reducing the environmental burden of PET bottles. PET bottles might have been singled out for study because their high volume to weight ratio and calorific value are important factors for landfill and incineration respectively. Studies to inform policy setting typically require scenarios which vary widely in order that a preferred direction of change can be determined. Less account may be taken of the practicality of achieving a particular scenario, and thus the scenario set need not necessarily be complete or realistic.	**Scenarios** 1. Current practice - assumed to be 100% landfill 2. Encourage incineration - incinerate 100% PET. 3. Encourage recycling - separate collection of mixed recyclables which are sent to a MRF and separated. PET is then recycled into fibre. 4. Encourage reuse - introduce reusable PET bottles which are delivered back to supermarkets and retailers.
Example 2 This application is set at a local authority decision making level. In response to government targets for diversion from landfill, the local authority is considering setting up a composting system. The scenarios set represent realistic options taking into account the time-scale and capital resources available.	**Scenarios** 1. Current practice 100% landfill. 2. Bring system for garden refuse and separate collection of park waste - mixed garden and park waste composted. 3. Separate collection of all putrescible and garden waste - mixed putrescible, garden and park waste composted. 4. Encouragement of home composting - through active encouragement (providing garden composters). A given percentage of households compost own garden and putrescible waste.

Recommendations
• The objectives and the final users of the study must be clearly and unambiguously defined.
• The inclusion or exclusion of alternative scenarios in a comparative study must be justified.

Scoping

3.5 During the 'scoping' exercise the study is planned to meet to its goals. The functional unit and the initial system boundaries are also set. It may not be possible to set the final system boundaries until the inventory stage and the main data collection process is underway. Nevertheless, all of the activities which comprise the system to be studied should be identified as far as is possible at this stage. In addition, the categories of environmental burden associated with these activities and the types, and eventual sources, of data should be considered at this stage and selected along with data quality goals.

Project planning

3.6 The requirement for critical review must be assessed early in the planning stage. If deemed appropriate, a critical reviewer or review panel should be chosen and involved during the scoping exercise. An assessment should be made as to whether the project team is appropriate or whether there is a need for additional expertise.

PROJECT PLANNING	
Example 1 Central government PET management	As this study is for the government and will feed into policy decisions it is important that a critical review be undertaken. It may also be advisable to set up an expert panel to involve the 'decision stakeholders'. In addition, as the system involves polymer processing stages, then the involvement of someone with expert knowledge in this area in the project team would be advisable.
Example 2 Local authority composting	At this stage the study is also to be used in decision making and a critical review would be recommended. Expert knowledge in the area of composting will be required.

Recommendations

- Critical review is recommended for all studies.
- Consideration of the involvement of stakeholders should be made where appropriate.
- Additional specialist knowledge should be brought into the project team where appropriate.

Functional unit

3.7 The functional unit is the reference point for all the inventory data and the remainder of the assessment. All scenarios in a comparison must have the same function, and the same functional unit, in order that like is compared with like. The functional unit should be defined in terms of the service delivered by the system where LCI is applied to waste management scenarios. Taking account of the goal of the study, for most waste management applications the functional unit will be a weight of waste arising, with a given composition, which must be dealt with.

FUNCTIONAL UNIT	
Example 1 Central government PET management	The functional unit might be determined on a unit weight of either mixed waste of given composition or the individual waste component (i.e., PET bottles). When the fourth scenario is considered (increased reuse) then it is obvious that the functional unit so defined is inadequate. As the main effect of reuse is to reduce the material entering the waste stream then the functional unit must reflect this change. A better definition of functional unit would therefore be the weight of waste or waste PET bottles produced by an average household over a given period (NB. If the fourth scenario is the principal focus of the study then consideration should be made of conducting a 'product' focused LCA rather than a waste management focused one, as this would allow better consideration of the functionality of the bottles).
Example 2 Local authority composting	The functional unit might be determined on a unit weight of putrescibles as this is the material that will be diverted. As the putrescibles are commingled with other waste types in some scenarios it may be conceptually easier to consider the functional unit as the weight of mixed waste containing a given weight of putrescibles. As in Example 1 one scenario involves the diversion of waste from the waste management system, in this case to home composting. The functional unit must therefore include all the compostable waste so that garden composting can be brought within the system boundary.

Recommendations

- The choice of the functional unit must be justified in relation to the goal of the study.
- The functional unit must provide the basis for comparison within a comparative study (i.e. it must be the same for all comparisons).
- For waste management applications the functional unit must be related to units of mass and not the volume of the waste.

System boundaries - initial definition

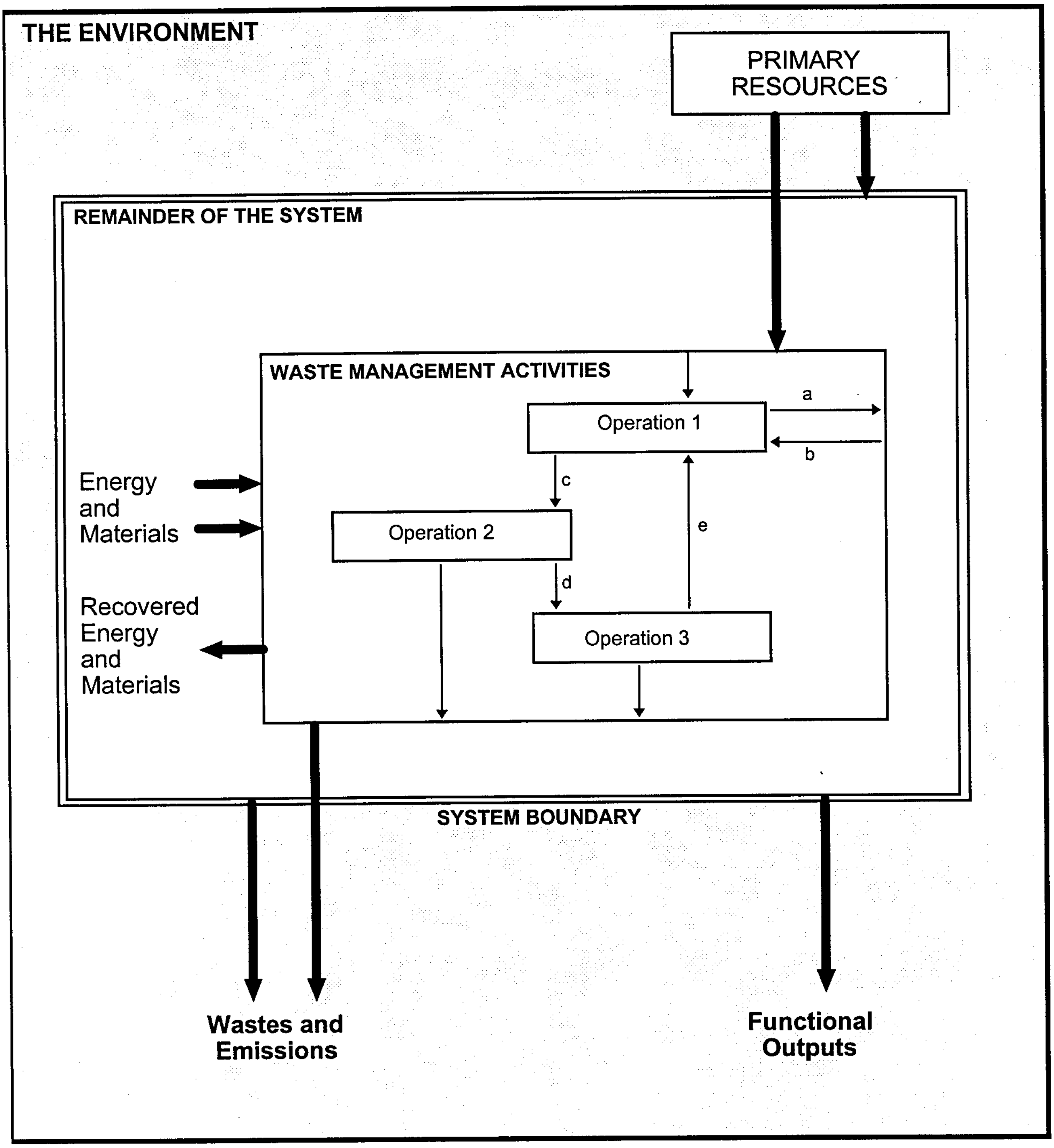
3.8 During the definition of the initial system boundaries the principal processes to be included in the system studied are identified. The waste management activities are likely to be at the centre of the system to be studied and the analysis will tend to focus on these 'foreground' activities. The remainder of the system, the background, represents the rest of the economic system which interacts with the waste management activities, for example, by exchanging energy and/or materials (Figure 3.1). Analysis may reveal that it is elements of the background system that have the greatest impact on the results of the study.

3.9 Waste management activities will include a number of different processes with materials and energy flows between them (i.e. inputs and outputs). Material flows which remain within the boundary of these waste management activities are known as *internal* or closed loop inputs and outputs. Transfers of materials between the waste management activities and the remainder of the system are known as intermediary inputs and outputs.

3.10 Material and energy inputs should, in principle, be traced back to the primary resources from which they are derived. Material and energy outputs should, again in principle, either be traced forward to their eventual 'grave' or to a point at which they can substitute for a recognisable material or energy stream. At this point they are considered to displace that material or energy stream and may cause a reduction in net emissions from those processes which were previously in place. Only in this way can the consequences of the waste management options being studied be fully accounted for, and other options justifiably compared. Thus extraction and production processes that are linked to waste management activities must be considered as part of the system. There will be system inputs associated, for example, with the capital items which are necessary to manage waste arisings, and reduced burdens consequent on recycling materials and recovering energy. The system boundary is thus drawn to include all the waste management activities and those further processes which constitute the remainder of the system.

3.11 In theory the system boundary should be defined such that nothing but elemental flows/environmental burdens cross it. In practice this is unlikely to be the case for reasons of practicality. The most obvious exception for most waste management studies is the waste itself, with waste generation, in general, explicitly excluded from the system. The system function is defined as the management of the waste which enters the system and leaves as environmental burdens. The system boundary is likely to exclude material and energy contributions to the system which are small enough that their inclusion or exclusion does not significantly affect the results of the study. These flows therefore do cross the boundary. Many minor material and energy flows will, however, not be identified until the main data gathering

Figure 3.1: System Boundaries for Waste Management



Note : Material flows a and b are 'open-loop'
Material flows c, d and e are 'closed-loop'

exercise is underway. Thus the final detailed system boundary cannot be defined until the inventory analysis stage is in progress. It is most important that the exclusion of flows from the system definition is justified in the report.

SYSTEM BOUNDARIES	
Example 1 Central government PET management	As this example concentrates on policy, and therefore changing waste management practice, capital items should be included. These may lead to significant differences between scenarios. Each scenario system must be carefully defined to include processes producing relevant direct and indirect burdens. For example: *Scenario 2* - involves new capital equipment, the incinerator, with potentially significant burdens. A distinct range of ancillary processes is required. Export of energy from the waste management operation expected to displace other forms of energy generated in the remainder of the system. *Scenario 3* - system boundary must be drawn to include 'normal' or alternate method of production of PET fibre. The system is then credited with the avoided burdens due to the use of recycled fibre. The system is thus functionally equivalent to the other scenarios because there is no change in overall PET fibre production. Equivalent performance of 'normal' and recycled fibre is a key assumption, and must be justified. *Scenario 4* - system boundary should include burdens from consumer activities in re-use, i.e. transport and bottle washing. Re-usable bottles must be more durable than one-way bottles and the necessary upgrading and increased transport burdens must be included in the system boundary.
Example 2 Local authority composting	Waste management operation and system boundary issues include; *Scenario 1* - collection of park waste is considered separately. *Scenario 2* - consumer transport should be included in the system. Data on this, together with information on material displaced by the compost, may prove difficult to obtain. Ancillary processes providing alternative sources of compost will be hard to identify and include in system. *Scenario 3* - will involve more complex kerbside collection. *Scenario 4* - alternative compost sources very hard to identify. Waste minimisation may have an effect on the waste management operations which need to be included in the system.

Recommendations

- The system boundaries must be defined such that, as far as possible, the function/functions of the systems to be compared are the same.
- Where differences in system boundaries between comparative scenarios are unavoidable these must be justified.
- Any distinction made between the operations to be considered for the waste management activities and the remainder of the system must be clearly reasoned and explained.

Burdens to be considered

3.12 During the 'scoping' stage, and before data collection begins, decisions must be made on which of the burdens arising from the processes included in the system boundary will require quantification.

3.13 When considering what should be included in the inventory, reference should be made to the goal of the study and particularly any decisions to be based on the results. The inventory should be focused on improving the basis of decisions, and not on providing superfluous data. For example, greenhouse gas data may be required if decisions are to be made on the basis of contributions to global warming. Account should be taken of any other complementary (non-LCA) tools to be used when determining the burdens to be considered. For example, direct financial considerations are likely to be dealt with by other means. Road congestion, when relevant, may be considered by a separate non-LCA study, and, if it is not, then data should be recorded in the inventory that will allow its consideration (e.g. urban road miles travelled during peak periods).

3.14 The environmental burdens included in the inventory will include:

- ***direct*** burdens arising from the waste management activities; plus,
- ***indirect*** burdens associated with the remainder of the system; and minus,

- ***avoided*** burdens – these are environmental burdens associated with the remainder of the system which are avoided because of recycling of materials or energy recovery taking place in the waste management activities.

BURDENS TO BE CONSIDERED	
Example 1 Central government PET management	It is likely that all major problem areas will need to be covered. Some issues may be met with other tools or through alternative means, the planning process for example. A focus on specific global or regional problems may be required depending on the demands of policy makers.
Example 2 Local authority composting	Local issues may be more significant. Non-flux flows such as odour may be important and may be considered in the treatment of direct burdens arising from the waste management activities. Issues such as visual impairment not dealt with in the inventory should be discussed.

Recommendations

- The burdens considered must relate to the goal of the study and particularly to any decisions to be based on the results.
- Consideration must be given to any other tools to be used in the decision making process.
- All burdens must be recorded in the inventory. The exclusion of burdens must be listed and explicitly justified in the report.
- Assumptions of flows displaced by materials leaving the waste management activities must be fully justified.
- Any material or energy flows across the system boundary must be clearly defined and mentioned in the report.

Data sources and quality goals

3.15 As part of the scoping stage, the source, type and quality of the data which are to be collected for different parts of the system should be determined. Sources of data should be identified and their use justified. Ideally, data specific to the materials and energy used in each activity within the system should be collected. Furthermore, marginal data should be used to reflect the real effect of changes brought about by the system, for example those sources of energy which are replaced when energy is recovered from incineration. In most cases these data are not available, given the resources which would typically be allocated to a study and, in practice, specific or average best practice data should be used wherever marginal data cannot be obtained.

3.16 Care should be taken to specify the correct source of data in the context of the scenarios which have been set, so that they are treated equitably. If new plant are assumed to be built the data sources should reflect this, rather than relying on data characterising older facilities. For avoided burdens however, the data source should reflect the replaced source of energy or materials, which may very well be older plant. Future scenarios should take account of technological developments that are likely to occur, albeit that data may be uncertain. The choice of data sources for waste management operations, imported material or energy and avoided burdens in the remainder of the system should be justified and be informed by the goal of the study and the scenarios which are to be compared.

DATA	
Example 1 Central government PET management	Use average UK data for all waste management operations. Use average data for materials and fuels used. Use average UK electricity mix for existing waste management operations demand. Use UK average marginal supply for changes brought about by system e.g. incinerator energy export from scenario 2 and energy savings through material export from scenario 3.
Example 2 Local authority composting	Use specific data for all waste management operations. Use average data for materials and fuels where specific data are not easily available. Although the scenarios do involve changes in the existing situation, there is unlikely to be a significant difference between the scenarios and the average UK electricity mix would therefore be appropriate data.

Recommendations

- Careful consideration should be given to the appropriateness of a particular data source in relation to the study.
- The choice of specific, average and marginal data should depend on the goal of the study and the scenarios being compared.

Reporting

3.17 The study should be reported in a manner which provides adequate transparency of methodology and data relative to the goal and intended application of the study.

3.18 The degree of transparency required in reporting will be influenced by the goal, intended use, and the intended audience of the study. Linking the detailed process flow diagrams to the Inventory Table of data is recommended. A graphical presentation of results often proves useful. One of the advantages of reporting the data in a transparent manner is that it facilitates subsequent determinations of the contribution to specific environmental impacts, broken into individual unit operations (or collections of unit operations), as well as for the system as a whole. The latter consideration, sometimes referred to as 'spatial awareness' in LCA, becomes important in the context of setting policy on the basis of geographical or commercial boundaries, rather than only on a global basis (which has tended to be the case where this technique has been employed in the past). For instance, a policy might be set on the basis of those activities impacting on the environment which occur in the UK only, and which therefore fall within the domain of the UK Government. Impact Assessment will be the focus for future studies to be commissioned by the Environment Agency under the life cycle research programme for waste management.

Recommendations

- The report must cover:

  the goal of the study, including the intended application; and,

  the scope of the study, including decisions on critical review, functional unit, choice of scenarios, system boundaries, burdens considered, data quality and assumptions.

- Results should be presented graphically wherever possible.

Inventory Analysis for Waste Management 4

Introduction

4.1 Following the definition of the Goal and Scope (Chapter 3), the next stage is to identify and quantify the environmental burdens associated with the systems being studied. This is the Inventory Analysis stage as defined in Chapter 2 and its aim is to quantify the resources used and the associated releases to air, water and land. Inventory Analysis is primarily a data gathering exercise. Its outcome should be a complete list of environmental burdens called an Inventory Table. It is generally recommended that the Inventory Table should be as complete and detailed as possible, consistent with the Scope and Goal of the study. As with Chapter 2, the reader should refer to the *Guidelines for Life Cycle Assessment : A Code of Practice* (SETAC, 1993) for further guidance on the general methodology for conducting LCA studies.

4.2 The process of Inventory Analysis can be described in terms of three key stages:

1. detailed definition of the system;
2. inventory compilation; and,
3. sensitivity analysis.

Each of these stages is discussed below, identifying issues which require particular attention in relation to waste management.

4.3 One general concern in applying Inventory Analysis to waste management, is the complexity likely to be encountered in any waste management option. This complexity arises from the wide range both of processes which may be employed and of materials in the different waste types. As a result of this complexity particular difficulty may be experienced in identifying comprehensively all the environmental burdens which need to be considered, because certain process steps or important waste/process interactions might be obscured. To counter this a method has been developed to standardise the description of waste management activities. This separates the physical processes involved from the types of waste being handled and breaks the physical processes down into a number of generic unit operations. This method is described in detail in Chapter 5 and is intended to provide a common language which can be used to describe different waste management activities consistently and in a way which facilitates the characterisation of environmental burdens.

Detailed Definition of the System

4.4 The simple flow diagram developed at the scoping stage (e.g. Figure 3.1) will need to be refined to include all the transport and other process steps which together comprise the waste management activities under study. For the more complex processes, the flow diagram will need to be broken down into sub-diagrams, using the generic unit operations described in Chapter 5.

4.5 Decisions will have to be made concerning which burdens associated with the production of capital and consumable items (e.g. process plant, vehicles, electricity, fuel, tyres, chemicals, etc.) used by the waste management activities are important. It is desirable that the range of burdens included should be made as comprehensive as possible at the outset, to avoid prejudging their significance. Sensitivity analysis might show that a burden from some activity is relatively trivial and that the activity can therefore be excluded from further consideration. In practice however, it is not usually until a substantial body of data has been built up that the sensitivity of the conclusions of the study to aspects of the inventory data can be properly examined. The recommendation is to attempt to identify and include all burdens unless they are demonstrated to be insignificant.

Non-flux burdens

4.6 LCI Inventory Tables are conventionally restricted to recording transfers of material and energy across the system boundary, so as to relate these to their environmental impacts. It should be recognised, however, that some environmental impacts such as land use, loss of habitat, visual disamenity, noise, odour, etc. are not usually quantified in LCA studies, and are not easily or directly linked to the Inventory Table of materials and energy raw data. Similarly, the environmental consequences of accidents are not conventionally included in Inventory Tables. However, it is these 'disamenity' or 'non-flux' impacts which frequently arouse most concern and debate when new waste management facilities are planned. It may be argued that other tools such as development controls and EIA procedures are better suited to handling these impacts. Nevertheless, it is recommended that Inventory Analysis, when applied to waste management, should as a minimum identify and highlight these impacts where they exist, although the Inventory Table itself will be restricted to data on materials and energy. See Annex 2, Vol. 2 for further consideration of this point.

4.7 The level of detail required when describing the system will depend on the Goal and Scope of the study. Using the example applications developed in Chapter 3, for Example 1, the waste management activities will not need to be described in great detail, because average data are to be used, although this should be stated clearly within the study and an evaluation made of the differences resulting from the best and worst case scenarios, equipment or plant. But for Example 2, where specific waste management systems are being compared, the scenarios should ideally be broken down into individual unit operations.

Recommendations

- The level of detail at which activities within the system boundary are described must be defined in relation to the Goal of the study.
- Use generic unit operations to describe the waste management activities taking place within the system boundary.

Data Collection and Calculation

4.8 All data collected must be fully documented. Data collected need to be expressed in terms of the functional unit before they can be compiled in the Inventory Table. Where it is necessary to apply a method to allocate burdens between co-products, co-inputs or co-outputs, this should be done, wherever possible, on the basis of physical causality. For example cadmium emissions from MSW incineration should obviously be allocated to the cadmium-containing items in the waste.

Inventory Compilation

4.9 Once the data have been collected they must then be compiled into the Inventory Table. But some forms of subsequent assessment may require the burdens to be broken down in some particular way, for example by country or area in which the burden is released. It is of fundamental importance that the data be held in a way that allows such a breakdown to be made.

4.10 In compiling the inventory, a profile is built up that quantifies the flow of materials through the system, with the *main* material output from one life cycle stage (e.g. process operation) becoming the *main* material input to the next life cycle stage. At the same time all other material and energy inputs and outputs occurring as releases to air, water and land are similarly quantified at each life cycle stage. In this way, the total quantity of 'inputs' at one life cycle stage should, by definition, equal the total quantity of 'outputs' occurring at that stage, i.e. they mass balance. Recognising the complexity of LCI methodology, this illustrates the importance of maintaining the transparency of reporting in LCI/LCA work (see Chapter 3). Not only should all raw data be evident (and able to be assigned against a given life cycle stage) but all elements of the calculation procedures, such as co-product allocation, should be transparent. One of the main reasons for conducting and reporting LCI studies in this manner is to maximise the potential for minimising burdens/impacts, by identifying where they occur at the most significant levels, i.e. to yield the greatest improvements by making the most beneficial use of resources.

Recommendations

- The range of environmental burdens included in the Inventory Table should be as comprehensive as possible.
- The data in the Inventory Table should be restricted to materials and energy flows, but 'non-flux' burdens must be recorded elsewhere.
- All data must be fully documented and assumptions detailed.
- Process data should ideally mass balance. Discrepancies should be viewed as potential data gaps.
- The data must be compiled in such a way as to allow disaggregation for further analysis.
- Allocation of burdens should be done wherever possible on the basis of physical causality.

Sensitivity Analysis

4.11 The sensitivity of the results to a particular factor or assumption may be assessed by varying the factor in question and examining the effect on the results of the study. Sensitivity analysis allows assumptions, methodology and data values (or data gaps) to be tested for significance in relation to the outcome of the study.

4.12 This testing of assumptions, methodological choices and data values serves two main functions. First it focuses attention on data and assumptions of key importance in relation to the overall outcome, so that time and effort can be devoted to collecting the most critical data. Second, the validity of key data and assumptions can be tested. For example, where results are highly dependent on particular data values, the data quality can be checked and, if necessary, steps taken to obtain more specific or more accurate data. This can be achieved by making a single change to data values (e.g. +/- 10%) and evaluating the consequences of this upon the end results. 'Decision rules' can then be employed that dictate that if the consequence of making a given change to data values is a net change of, say, more than 30% to the end results, then those data should be examined more closely in relation to their quality. Indeed, in this way, data values can be selected which might then form the basis of a concerted programme of data collection (rather than seeking to gather measured, site-specific data for *every* data value that has been otherwise drawn from a data base). To illustrate the usefulness of this approach, it should be remembered that in most LCI/LCA studies the number of individual data values employed is in the order of several hundred or even thousand. Illustrations of the application of the techniques of sensitivity analysis to Examples 1 and 2, are described below.

4.13 **Example 1.** The sensitivity of scenario 1 to the method of handling the burdens arising from landfill (especially time-dependent burdens), could be investigated by modelling the extreme situations, i.e. assuming no mineralisation vs. complete mineralisation of the PET bottle in the landfill. The significance of a complete process, and the implications for the level of detail required can also be investigated. For example in scenario 3, the burdens arising from the MRF might be shown to be so low, relative to the burdens arising from other recycling steps, that detailed investigation of the MRF burdens directly related to PET bottles is unnecessary.

4.14 **Example 2.** In scenario 2 the potential problems of finding and collecting data regarding the material replaced by compost, could be tackled by testing the significance of the results to a range of estimated data values. The decisions to include or exclude the burdens arising from the production of consumables could also be tested. For example, the significance of excluding items such as bags and ties should be tested, even if this is only done to provide the justification for their exclusion.

Recommendations

- All assumptions and allocation choices and areas of data uncertainty should be tested by sensitivity analysis as an integral part of the study.

The Description of Waste Management Activities 5

Introduction

5.1 The initial definition of the processes to be included in the system under study (i.e. the system boundaries, see Chapter 3) reveals a clear distinction between the waste management activities proper (for example, the collection and transportation of wastes, the operation of transfer stations, incinerators, landfill sites, MRFs, etc.) and other activities within the overall economic system. The latter are necessary because they provide materials and/or energy for the waste management activities (for example the generation of grid electricity, provision of public water supplies, the production of items of capital equipment and consumables, etc.).

5.2 These two groups of activities are shown separately in the simple flow diagram which represents the initial definition of system boundaries, as 'waste management activities' and the 'background system' respectively (see Figure 3.1). Environmental burdens which result from the waste management activities are known as **direct burdens**, and those resulting from the background system as **indirect burdens**. If the waste management activities also contribute energy or materials to the background system, for example, electricity generated from the incineration of wastes, which displaces grid electricity generated from power stations in the background system, then the indirect environmental burdens which are thus avoided are credited to the system and recorded as **avoided burdens.**

5.3 The Inventory Table of environmental burdens for any waste management option under study, therefore comprises three main elements:

- **direct environmental burdens** – from waste management activities;
- **indirect environmental burdens** – from the background system; and,
- **avoided burdens** – which account for energy and materials displaced from the background system by the waste management activities.

Classification of Environmental Burdens

5.4 For any waste management system under study, the direct burdens associated with waste management activities will depend on both the physical processes being undertaken and the nature of the wastes being processed.

These factors will also determine the source of the indirect burdens experienced and, to an extent, their magnitude. For example, the types of burden associated with the production of grid electricity in the UK remain fixed over the short-medium term (dependent on the mix of generating plant), but the magnitude of these burdens debited to any given waste management system will depend upon the amount of electricity consumed or generated by the waste management activities.

5.5 As the number of different processes which might be embraced by the waste management activities is very great and the range of waste types ultimately covers all materials used and created by industrial societies, it follows that a very wide range of both direct burdens and indirect burdens may arise from any system under study. This complexity presents a challenge for Inventory Analysis in ensuring that different sets of waste management activities are analysed consistently and that all the environmental burdens arising within the system boundary are identified.

5.6 Moreover, the diverse nature of the environmental burdens relevant to decision making in waste management raises questions about which of the burdens identified requires detailed quantification and whether any may be justifiably excluded from a particular LCI study. For example, in LCI the term ‘environmental burden’ conventionally refers to resources and emissions that cross the system boundary as a physical flow or flux and are thus amenable to quantification. There are, however, burdens that do not flow across the system boundary, for example, visual intrusion and traffic congestion, which may have very significant local impact. These non-flux burdens are more difficult to quantify and indeed, their significance may depend heavily on local public opinion. Some flux burdens, such as noise, litter, fugitive dust and odour, also fall into a similar category, where again the impact is highly dependent on the local situation and public perception. These burdens are often excluded from LCI studies, or simply recorded under the general heading of disamenity (see Chapter 4). But in the context of waste management it is these non-flux burdens that frequently cause most public concern, especially when new facilities are being planned.

5.7 A further classification of the environmental burdens arising from all of the activities within the system boundary is therefore required to assist in burden identification, in making decisions about the appropriate level of quantification required and to ensure that decisions to exclude burdens are taken in a transparent manner and properly justified. This classification will also assist in studies where there is a desire to allocate burdens to specific components of MSW (paper, glass, batteries, etc.).

For direct burdens, three broad categories may be identified:

- ***Fixed burdens***
  These are 'process related burdens' that arise due to the physical existence of the operation alone (for example, visual intrusion, land use and burdens associated with construction and decommissioning);

- ***Waste independent burdens***
  These are 'process related burdens' due to the quantities of waste flowing through the operation irrespective of the specific characteristics of the waste (for example power consumption of handling equipment, transport vehicle emissions, traffic congestion); and,

- ***Waste dependent burdens***
  These are 'product related burdens' due to the combination of unit operation, throughput and the nature of the waste (for example, incinerator stack emissions of CO_2, heavy metals and HCl, consumption of alkali during neutralisation processes or odour from a compost plant).

5.8 This classification is developed further in Chapter 6. Here a method of identifying environmental burdens according to the classification is developed and guidance given on sources of data and techniques for quantifying the burdens. In addition, advice is provided on appropriate methods for allocating burdens to the specific components found in waste if the goal of the study requires this information.

5.9 However, the essential starting point for the identification, quantification and allocation of direct, indirect and avoided burdens is that the set of waste management activities within the system boundary under study should be described in a systematic and consistent way. A method to achieve this is described below.

Twin-track Approach

5.10 The waste management activities comprise both the plant and processes being utilised and the wastes being handled. A method is therefore required to describe both of these elements in tandem, bearing in mind that the characteristics of the waste being processed may change markedly as it passes through the system (for example, after incineration, composting, separation, etc.).

A 'twin-track' system has been therefore been developed, which is capable of describing any set of waste management activities as a combination of:

1. generic unit operations; and,
2. wastes with generically defined characteristics undergoing the unit operations.

5.11 The main benefit of this approach is that it can be used to describe in detail any specific waste management activity, either existing or planned, in a consistent manner. Thus, for example, specific changes to the configuration of an existing incinerator, or a new incinerator design which differs in certain respects from the current norm, can be accommodated, as can changes in the composition of the wastes being treated. This avoids the need to base decisions only on composite data for 'average' plant of a given type handling a 'typical' waste. For example, for stack emissions from average UK MSW incinerators.

Unit Operations

5.12 The full range of waste management activities which may be encountered in any waste management scenario has been systematically broken down into a defined number of generic unit operations. Eight main categories of waste management activity have been defined: three transport categories (road, rail and water) and five waste processing categories (physical, thermal, chemical, biological and storage). Within these categories a total of 45 generic unit operations are identified (Table 5.1).

5.13 The unit operations defined in Table 5.1 are waste independent descriptions of all the operations that might be required to undertake waste management activities. They are intended to be used as building blocks from which to compile detailed flow diagrams describing each separate element within the set of waste management activities identified for the system under study. For example, in the case of a set of waste management activities that includes an aerobic composting step, the composting activity would be described by the flow diagram shown in Figure 5.1. It can be noted that 8 different unit operations (used a total of 17 times) from 4 process categories are required to describe fully the composting activity (Table 5.2). A full worked example using a complete waste management option is given in Chapter 8.

Table 5.1: Process Categories and Generic Unit Operations

PROCESS CATEGORY		UNIT OPERATION	
UO1	**Road Transport**	A	Private motor vehicle
		B	Refuse freighters (RCV*, FEL*, Skip)
		C	Bulk freighters
		D	Tankers
		E	Van/lorry
		F	Large tractor
		G	Small tractor/forklift truck
		H	Specialist landfill mobile plant
UO2	**Rail Transport**	A	Locomotive drawn train
UO3	**Water Transport**	A	Self-propelled vessel, with/without towed barges
UO4	**Physical Processes**	A	Mixing
		B	Separation
		C	Size reduction
		D	Compaction
		E	Conveying
		F	Cooling
		G	Energy transfer
UO5	**Thermal Processes**	A	Combustion
		B	Gasification
		C	Pyrolysis
		D	Calcining
		E	Drying
		F	Microwaving
UO6	**Chemical Processes**	A	Neutralisation
		B	Oxidation
		C	Reduction
		D	Precipitation
		E	Catalysis
		F	Hydrolysis
		G	Hydrogenation
		H	Electrolysis
		I	Ion exchange
		J	Vitrification
		K	Pozzolanic
		L	Cementitious and other build-up reactions
		M	Other breakdown reactions
		N	Other substitution reactions
UO7	**Biological Processes**	A	Aerobic
		B	Anaerobic
		C	Enzymatic
		D	Vermiculture
		E	Fermentation
UO8	**Storage**	A	Fully contained
		B	Semi-contained
		C	Open

Note: *RCV = 'Refuse Collection Vehicle'
*FEL = 'Front End Loader'

Figure 5.1: Description of Aerobic Composting Process Using Generic Unit Operations

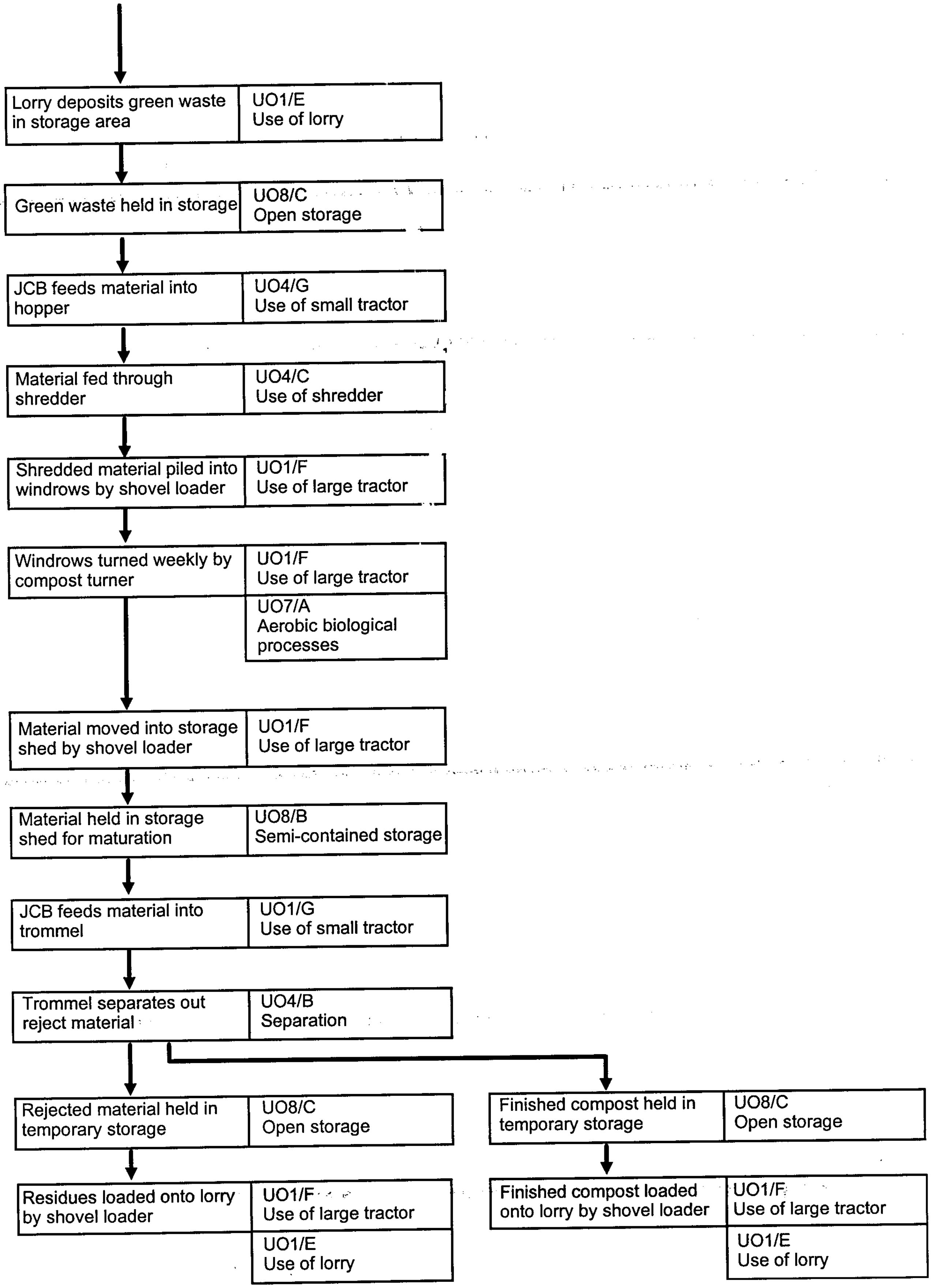


Table 5.2: Summary of unit operations used to describe the green waste aerobic composting process shown in Figure 5.1

Unit Operation		Description of Activity
TRANSPORT PROCESSES		
UO1/E	Use of lorry	Lorry manoeuvring on site to deposit green waste in storage area
UO1/E	Use of lorry	Lorry manoeuvring on site to load finished compost
UO1/E	Use of lorry	Lorry manoeuvring on site to load reject material
UO1/F	Use of large tractor	Shredded green waste piled into windrows
UO1/F	Use of large tractor	Windrows turned weekly by compost turner
UO1/F	Use of large tractor	Composted material moved under cover for maturation
UO1/F	Use of large tractor	Finished compost loaded onto lorry
UO1/F	Use of large tractor	Reject material loaded onto lorry
UO1/G	Use of small tractor	JCB feeds green waste into hopper before shredding
UO1/G	Use of small tractor	JCB feeds composted material into trommel for screening
PHYSICAL PROCESSES		
UO4/B	Separation	Plastics and other debris separated from composted material by trommel
UO4/C	Size reduction	Green waste passed through shredder
BIOLOGICAL PROCESSES		
UO7/A	Aerobic processes	Aerobic microbiological processes occurring within windrows
STORAGE PROCESSES		
UO8/B	Semi-contained storage	Composted material matured in shed for 6 weeks
UO8/C	Open storage	Green waste held in piles awaiting processing
UO8/C	Open storage	Rejected material held in piles awaiting onward transport
UO8/C	Open storage	Finished compost held in piles awaiting onward transport

5.14 For some studies, identification and, more particularly, the quantification of environmental burdens, may require additional information or descriptors to qualify the unit operations given in Table 5.1. For example, in the case of road transport, information about the engine type (for example petrol, diesel, electric) or the operational mode (for example stop/start collection vs. motorway driving), may be required to identify burdens at a finer level of detail, depending on the goal and scope of the study. A set of additional descriptors for each unit operation is therefore provided in Table 5.3.

5.15 The way in which the Tables should be used to determine the level of discrimination typically required for the Inventory Table is best illustrated using an example. The activity of collecting waste from households could be described as: a diesel-fuelled RCV operating in stop/start mode, with the container body semi-open to permit loading. Using the codes given (Tables 5.1 and 5.3), this would be defined as: UO1/B-a,f,n. The activity of the loaded vehicle returning to a transfer station may be described as a diesel-fuelled RCV operating in urban driving mode, with the body closed, i.e.: UO1/B-c,f,l. Once at the transfer station, the activity may be described as a diesel-fuelled RCV in manoeuvring mode, with the body open to permit unloading, i.e.: UO1/B-b,f,m. For this example, apart from a higher risk of spillage during collection, the type of burdens that occur in stop/start mode and urban cycle mode are the same (i.e. vehicle emissions, noise, congestion, traffic accidents, manufacture of the vehicles, production of diesel fuel), but the magnitude of most of these burdens will be different. For the manoeuvring mode, traffic congestion drops from the burden list.

Waste Descriptions

5.16 The wastes passing through a given waste management option are described in terms of the main generic characteristics relevant to the identification of environmental burdens. Ten waste characteristics have been identified (Table 5.4) and any given waste can be described using a combination of these characteristics. For example the green waste passing through the composting process shown in Figure 5.1 would be coded as WC1/WC2/WC3/WC7/WC8, i.e.:

WC1 physical form	potential for dust
WC2 moisture content	value will affect dust, biodegradability and leachate levels
WC3 biodegradability	potential for odour, gas and leachate
WC7 leachability	solubility affects leachate burdens
WC8 sterility	potential for pathogens to affect human health

5.17 It should be noted that the characteristics selected to describe wastes in Table 5.4 are not fully independent. For example, a biodegradable waste will also have a calorific value (i.e. be combustible). In the same way, the

Table 5.3: Unit Operations - Additional Descriptors

UO1 ROAD TRANSPORT	UO2 RAIL TRANSPORT	UO3 WATER TRANSPORT	UO4 PHYSICAL PROCESSES	UO5 THERMAL PROCESSES	UO6 CHEMICAL PROCESSES	UO7 BIOLOGICAL PROCESSES	UO8 STORAGE PROCESSES
OPERATIONAL MODE a Stop/start collection b Manoeuvring /handling c Urban driving d Rural driving e Motorway driving	*OPERATIONAL MODE* a Long distance hauling b Marshalling /shunting	*OPERATIONAL MODE* a River b Canal c Estuary d Sea	*PHASE OPERATION* a Solid b Sludge c Liquid d Gas/high solids e Gas/low solids	*PHASE OPERATION* a Solid b Sludge c Liquid d Gas/high solids e Gas/low solids	*PHASE OPERATION* a Solid b Sludge c Liquid d Gas	*PHASE OPERATION* a Solid b Sludge c Liquid d Gas	*PHASE OPERATION* a Solid b Sludge c Liquid d Gas
FUEL TYPE f Diesel g Leaded petrol h Unleaded petrol i LPG/NG j Electric k Oil	*FUEL TYPE* c Diesel d Electric	*FUEL TYPE* e Diesel f Oil	*FUEL AND OTHER ANCILLARIES* f Electricity g Diesel h Lubricants i Water j Chemicals	*FUEL AND OTHER ANCILLARIES* f Electricity g Diesel h Lubricants i Water j Chemicals	*ANCILLARIES* e Inorganic chemicals f Organic chemicals g Electricity	*ANCILLARIES* h Closed i Open j Semi-open	*DURATION* e Short, 1 week f Medium, 6 months g Long, 5 years
BODY TYPE l Closed m Open n Semi-open	*WAGON BODY TYPE* e Open f Closed	*HOLD TYPE* g Open h Closed			*REACTOR VESSEL* h Closed i Open j Semi-open		

property of volatility may or may not be associated with flammability and/or combustibility, depending on whether the volatile compounds are organic or inorganic. For many mixed wastes, most, if not all, the characteristics listed in Table 5.4 will apply to a greater or lesser degree. Moreover, a given waste may be transformed by a treatment process and its characteristics changed as it moves through the waste management process (for example, combustible waste becomes non-combustible waste after thermal processing, but leachability increases because of the increase in concentrations of soluble, toxic metals and other species, particularly chlorides in the ash products).

Table 5.4: Generic Waste Characteristics

CODE	CHARACTERISTIC	MAIN POTENTIAL BURDEN EFFECTS
WC 1	PHYSICAL FORM	Liquid, solid, size, shape, density, hardness, strength etc., may have significant effect on power/fuel demand of transport and handling processes and the potential for litter, dust, noise during processing by operations.
WC 2	MOISTURE CONTENT	Low values may increase dust/litter potential. High values indicate increased biodegradability and leachability.
WC 3	BIODEGRADABILITY	Associated with odour, gas emission and leachate releases. May attract vermin. Will thermally degrade creating similar burdens to combustible waste.
WC 4	COMBUSTIBILITY	Wide range of gas/liquid/solid products with potential for contributing burdens to all media during thermal processes. Includes odour and volatiles on drying.
WC 5	CHEMICAL REACTIVITY	Reaction products on mixing with other wastes, reagents or exposure to air/water may lead to burdens to all media. May also create burdens if subject to thermal process even if no combustible content.
WC 6	TOXICITY	If toxic elements or compounds present (refer to controlled releases to air/water/ground) form of potential release to environment affects burdens and burden level.
WC 7	LEACHABILITY	Solubility of components affects burdens and level of burden.
WC 8	STERILITY	Exposure to animals/humans to the waste may create health burdens, may be factor attracting vermin.
WC 9	VOLATILITY	Potential burdens created during storage, may create fire/explosion risk, odour and increase exposure to health risks.
WC 10	FLAMMABILITY	Fire/explosion risk during storage and physical processes that generate heat/sparks.

The Identification and Characterisation of Environmental Burdens 6

Introduction

6.1 In Chapter 5, the 'twin-track' approach was used to develop a method for describing any system comprised of a number of waste management options as a combination of generic unit operations and wastes with generic characteristics undergoing those operations. Describing the waste management activities within the system boundary in a systematic and consistent manner is an essential starting point in the identification of the direct, indirect and avoided environmental burdens which arise from all of the activities included within the system boundary under study. In particular, the twin-track methodology enables direct burdens to be differentiated on the basis of whether they are independent or dependent of the characteristics of the wastes being processed.

6.2 In this Chapter, more detailed guidance is given on how to use a) the twin-track method for describing waste management activities; and b) the classification of burdens as waste independent and waste dependent, to identify and quantify the direct, indirect and avoided burdens which arise from the system under study and which need to be included in the Inventory Table. Finally, advice is provided on appropriate methods for allocating burdens to specific components of MSW, if this is required by the Goal and Scope of the study.

Detailed Classification of Environmental Burdens

6.3 The basic division of burdens into waste independent and waste dependent, can be refined to produce a more detailed classification of burdens that will further assist burden identification and decision making (Table 6.1). For waste independent burdens (i.e. burdens that are inherent in the buildings and plant used, or which depend only on the quantities of waste handled), it is useful to distinguish between *fixed* burdens and *variable* burdens and to consider whether the burden is capable of physically crossing the system boundary (i.e. is a *flux* burden) or not (a *non-flux* burden).

Fixed burdens

6.4 Fixed burdens are those which arise because of the physical existence of facilities, including their initial construction and ultimate decommissioning.

The magnitude of these burdens does not change during the operation of the system and they should therefore be allocated to the total waste processed over the lifetime of the system. Significant burdens will cover:

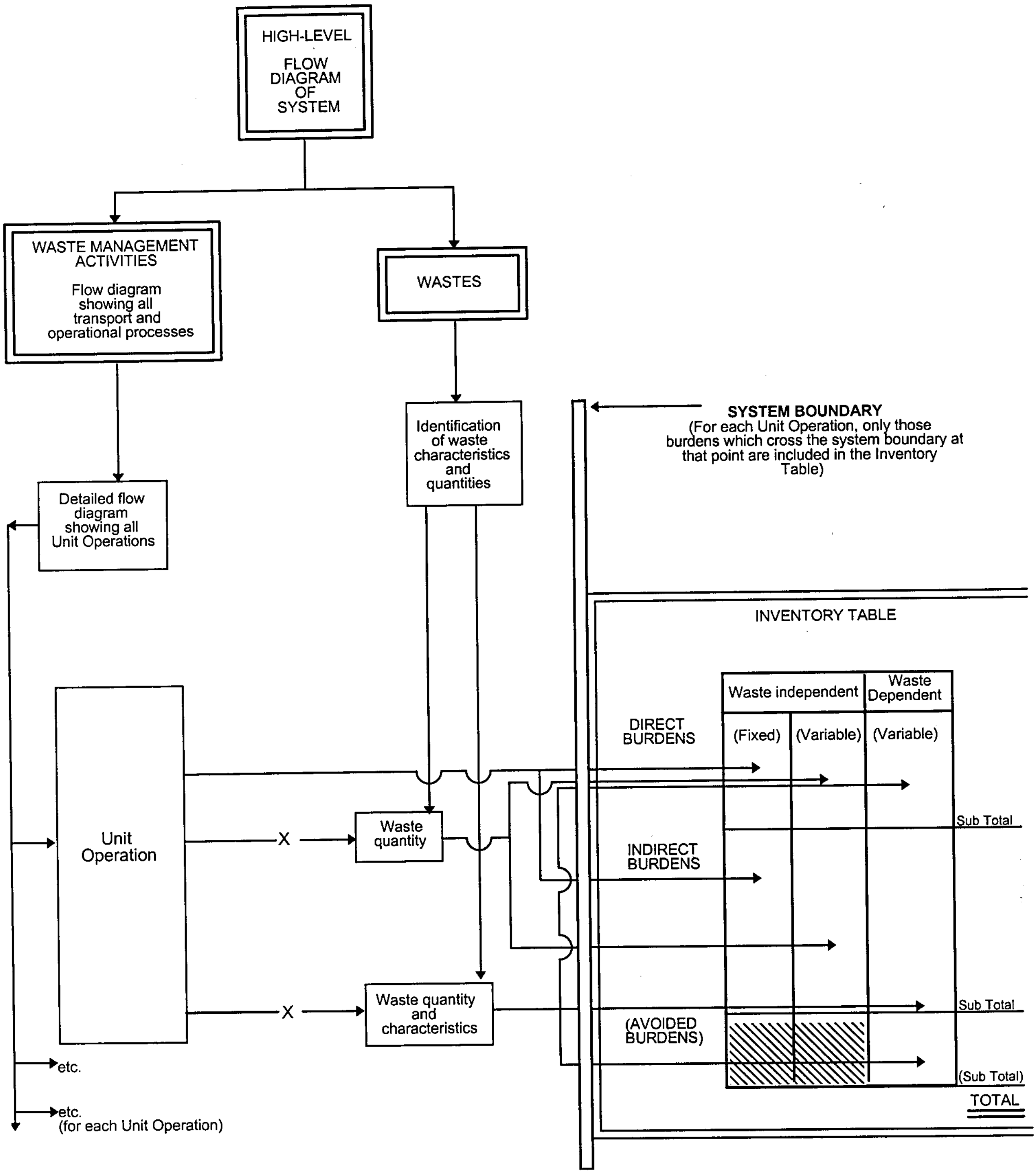
Flux
- noise and dust from construction and demolition
- local air pollution from construction and demolition vehicles
- generation of construction and demolition wastes
- generation of waste oil, lubricants, hydraulic fluid, tyres and batteries from construction and demolition vehicles

Non-flux
- visual intrusion (e.g. the presence of incinerator stacks)
- land-take for development
- traffic congestion from construction and demolition vehicles

Waste independent burdens

6.5 These burdens are independent of the type of waste flowing through the waste management operations. These include burdens that depend on factors such as plant running time and distances travelled and include burdens associated with providing power to equipment, fuel for vehicles, vehicle emissions and other consumables required to maintain such activities. They also include burdens which, though more closely associated with the waste, vary only within a very narrow range. These burdens have been considered in detail by Eggels and van der Ven (1994) for the case of waste incineration (see also Annex 3, Vol. 2). Eggels and van der Ven label these burdens as 'process related', because the emission is primarily controlled by the design of the process and changes little with varying waste composition. Emissions of dioxins and particulates from incinerator stacks are examples of process related burdens.

Figure 6.1: Compilation of the Inventory Table



Flux
- incinerator stack emissions of CO, Dioxins and particulates
- fugitive dust and odour from most types of process
- noise from the operation of plant and vehicles
- local air emissions from vehicles
- oil on roads from vehicles
- generation of waste oil, lubricants, hydraulic fluid, tyres and batteries from vehicles and plant

Non-flux
- traffic congestion

Waste dependent burdens

6.6 All waste dependent burdens are flux burdens. It should be noted that a number of such burdens (for example, fugitive dust and odour) are extremely difficult to quantify without site-specific survey data and have conventionally been dealt with in LCIs by grouping them together with waste independent non-flux burdens (for example, visual intrusion and traffic congestion) under the general heading of 'disamenity'.

6.7 The major waste dependent burdens are among those emissions, discharges and the production of residues produced from processing wastes by waste management operations. The extent to which they actually vary with waste composition depends upon the operating conditions. An important distinction can be drawn between those burdens which vary within a narrow range only and are classified as process dependent (see section 6.5) and those which vary within a wide range of possible values (Table 6.1). Burdens which vary within a wide range are labeled 'product related', because the magnitude of these burdens is more directly related to the level of specific components in the waste. For example the level of CO_2 emission from incinerators depends on the carbon content of the waste, and ferrous metal recovery depends on the amount of ferrous metal in the waste. Product related burdens also include those burdens associated with the use of resources that are only consumed in the process because they react with components in the waste and/or become part of the waste or product (for example, alkali consumption in a gas scrubber).

Waste dependent flux burdens

- incinerator stack emissions of CO_2, SO_2 and heavy metals
- gas scrubber residues from incineration
- emissions of CO_2 and CH_4 from anaerobic digestion
- generation of landfill gas
- generation of landfill leachate

Compilation of the Inventory Table

6.8 The compilation of the Inventory Table requires that all the potential burdens that originate within the system boundary are identified and quantified. The overall process is summarised diagrammatically in Figure 6.1, showing how the description of waste management activities as a series of waste-independent unit operations, each handling wastes with specific characteristics, can lead to the identification and quantification of burdens according to the classification of burdens given in Table 6.1. Further guidance is given below on how environmental burdens are identified and then quantified for given systems comprising various combinations of unit operation and waste type.

Identification and quantification of environmental burdens

6.9 From the detailed classification of burden types given above, it can be noted that the *waste independent* burdens, like those associated with the consumption of resources used (indirect burdens) and emissions from transport equipment (direct burdens), are essentially additive. Thus, the total electricity demand for any system is the sum of the demand of individual unit operations, and the total vehicle emissions is the sum of emissions from all the transport stages. Hence, knowledge and data for individual unit operations in a system can be used directly to obtain the total burdens entered into the Inventory Table and such data will have wide applicability for different systems.

6.10 In contrast, the *waste dependent* burdens are mainly associated with the release of waste, or components/reaction products of waste, into the environment and depend upon the precise composition of the waste going through a particular part of the waste management system. These burdens cannot be quantified by considering the individual unit operations and the original waste characteristics in isolation, as stand-alone elements of the

Table 6.1: Classification of burdens to assist inventory data collection

BURDEN CLASSIFICATION		EXAMPLE	INFORMATION NEEDS	POTENTIAL SOURCES
FIXED	FLUX	Resources used in capital equipment	Unit operations used and associated construction work	General data from a wide range of sources including non waste management sources
	NON FLUX	Visual intrusion created by the facility	Location of site/activity	
WASTE INDEPENDENT BURDENS (PROCESS RELATED)	NON FLUX	Traffic congestion	Location of site/activity	General data from a wide range of sources, limited data on bulk waste to permit conversion to functional unit
	FLUX	Fuel used and associated emissions from transport	Frequency/duration of unit operations and waste flow rate	
WASTE DEPENDENT BURDENS (PRODUCT RELATED)	FLUX	CO, dioxins, particulates from MSW combustion, fugitive dust and odour	Unit operations comprising the process, waste type and throughput	Legislation and limit values, measured data
		CO_2, CH_4 from anaerobic digestion. Acid gas cleaning chemical demand	Unit operations comprising the process, waste type and throughput of specific components in the waste	Monitoring data, detailed composition data, process models

system. This is because potential burdens produced in any particular unit operation may not cross the system boundary at that point, but rather be transferred as an input to a subsequent unit operation. This may also change the waste characteristics and quantities passing through subsequent unit operations within the system. For example, household waste in one system may result in major or minimal emissions of methane at a landfill, depending on upstream processes carried out on the original waste stream (for example segregation and diversion of putrescibles) and the control systems adopted to manage the biogas produced in the landfill. Therefore, in practice, it is important that having identified a potential burden arising as a result of a given unit operation or combination of unit operation and wastes with specific characteristics, consideration is given to whether the burden actually crosses the system boundary at that point.

Identification of waste independent burdens

6.11 The starting point for the identification of waste independent burdens is to describe the physical processes involved using the unit operations given in Table 5.1 and the additional descriptors given in Table 5.3. Each unit operation so identified gives rise to a number of burdens which can then be recognised and quantified without detailed knowledge of the waste characteristics. These will include burdens associated with production of capital items, fuel use and related emissions, the production of electricity and other consumables such as tyres, lubricants, batteries, etc., noise, congestion and other disamenities. Sources of the principal waste independent burdens associated with the main categories of unit operations are given in Table 6.2.

Quantification of waste independent burdens

6.12 **Fixed burdens** - as noted, fixed burdens associated with the capital infrastructure are often excluded from consideration within conventional LCI studies, but this is unlikely to be acceptable in the context of waste management. The Inventory Table information required for *non-flux* fixed burdens may be confined to a comment on major features. For example, a statement recording the presence of a 100m chimney in a densely populated area, and/or the consumption of 3 acres of green-belt land (in the case of an incinerator proposal). Non-flux burdens associated with construction and decommissioning should also be treated in the same way, for example, data on traffic movements. This would suffice to alert the user that these factors exist and a decision can then be made as to whether a separate impact assessment should be carried out in subsequent stages of the LCA, or whether these burdens would be better dealt with using another decision tool, for example the statutory Environmental Impact Assessment and other planning procedures.

6.13 For *flux* fixed burdens it is recommended that initial consideration is confined to assessing the tonnage of the main commodity materials used to build the system, for example, concrete, steel, plastics, wood, etc. From these data a broad assessment of the indirect burdens associated with energy demand, extraction of raw materials from the environment and associated emissions should be sought from the relevant industry or from academic/government sponsored studies.

6.14 These data can then be used to make an initial assessment of whether, compared with the active life of the facility, the resource use and associated burdens are significant in terms of the goal of the study.

6.15 **Flux burdens** - flux burdens always require quantification and need to be expressed in terms of the relevant functional unit. For many of the unit operations, relevant data in relation to the indirect burdens may already be held by equipment manufacturers and other researchers. For example, belt conveyors of a given load design capacity in any process, whether for conveying wastes, minerals or any other materials, have very similar power demands in terms of energy consumption per hour and data are readily available from equipment manufacturers, etc. Thus the treatment of most of these indirect burdens will not differ fundamentally in an LCI of waste management from the treatment of indirect burdens in other LCI studies. For example, the indirect burdens associated with the production of grid electricity in the UK will differ only in degree (depending on the relative amounts of electricity consumed), between waste management LCIs and other LCI studies based in the UK. Therefore, the treatment of indirect burdens in waste management LCIs should draw, wherever possible, on existing knowledge and data about activities within the remainder of the economic system. In time, it should be possible to provide default database information that can be used to quantify these burdens given knowledge of waste throughput, transport distances, and operating hours.

6.16 **Non-flux** burdens - for *non-flux* burdens, it will normally be sufficient to record those aspects of the unit operations that will alert the user to consider these for disamenity or other purposes. For example, transport mileage data would be recorded to allow subsequent assessment of congestion and road traffic accidents.

Table 6.2: Sources of Some Fixed Burdens Associated with the Main Categories of Unit Operations

	FIXED BURDENS
UO1 ROAD TRANSPORT	• Capital resources associated with vehicle and garaging • Land take for depot, visual intrusion of depot
UO2 RAIL TRANSPORT	• Capital resource use in train and rolling stock, track and marshalling facilities • Land take and visual intrusion
UO3 WATER TRANSPORT	• Capital resource use in vessels and docking facilities • Land take and visual intrusion
UO4 PHYSICAL PROCESSES	• Capital resources for process equipment and associated buildings • Land take and visual intrusion
UO5 THERMAL PROCESSES	• Capital resource use for thermal operation, associated equipment and building • Land take and visual intrusion
UO6 CHEMICAL PROCESSES	• Capital resource use for chemical process, associated equipment and buildings • Land take and visual intrusion
UO7 BIOLOGICAL PROCESSES	• Capital resource use for bioprocessing facilities and associated equipment and building • Land take and visual intrusion
UO8 STORAGE	• Capital resource use for storage facility • Land take and visual intrusion

Table 6.3: Sources of Some Variable Burdens Associated with the Main Categories of Unit Operations

	VARIABLE BURDENS (related to waste throughput and/or composition)
UO1 ROAD TRANSPORT Note: Distance travelled/hours operated in the various modes are the main determinants of burden levels.	FLUX burdens: • Fuel use and related emissions • Payload may affect fuel *use* per km but this is likely to be a marginal effect compared with use per kg/km • Other consumables (e.g. oil, tyres, water, chemicals) • Noise • Fuel/lubricant leakage to roadway • Mud on roads • Fugitive odour, dust, litter, liquid release • Waste characteristics may increase risk in accident situation • Waste characteristics associated with fugitive burdens, especially WC1, WC2, WC3, WC6, WC9 • In accident conditions all waste characteristics may be relevant, but toxicity (WC6) and flammability (WC10) are probably the key ones NON-FLUX burdens: • Traffic congestion • Traffic accidents
UO2 RAIL TRANSPORT Note: Distance travelled/hours operated in the various modes are the main determinants of burden levels.	FLUX burdens: • Fuel use and related emissions • Payload in rail transport may affect fuel *use* per km but use per kg/km in bulk rail transport systems likely to be low and relatively stable • Other consumables (e.g. oil; water etc.) • Noise unlikely to be significant for rail transport • Train related effluents released onto trackbed • Very low potential for fugitive odour, dust, litter, liquid releases • Waste characteristics associated with fugitive burdens, especially WC1, WC2, WC3, WC6, WC9 • In accident conditions all waste characteristics may be relevant but toxicity (WC6) and flammability (WC10) are probably the key ones NON-FLUX burdens: • Congestion and accidents are not likely to be significant for rail transport

Table 6.3: Sources of Some Variable Burdens Associated with the Main Categories of Unit Operations (continued)

	VARIABLE BURDENS (related to waste throughput and/or composition)
UO3 WATER TRANSPORT Note: Distance travelled/hours operated in the various modes are the main determinants of burden levels.	FLUX burdens: • Fuel use and related emissions • Payload in water transport may affect fuel use per km but use per kg/km in bulk water transport systems likely to be low and relatively stable • Other consumables (e.g. oil; water etc.) • Discharge of ship-related effluents to surface waters • Noise unlikely to be significant for water transport • Very low potential for fugitive odour, dust, litter, liquid releases • Waste characteristics associated with fugitive burdens especially, WC1, WC2, WC3, WC6, WC9 • In accident conditions all waste characteristics may be relevant but toxicity (WC6) and flammability (WC10) are probably the key ones NON-FLUX burdens: • Congestion and accidents are not likely to be significant for water transport
UO4 PHYSICAL PROCESSES	FLUX burdens: • Electricity use • Fuel use and related emissions • Throughput may affect power demand in terms of kW/hr for processes such as size reduction/compaction but for most separation and conveying operations kW/hr levels change little with increased feed rate/loading of the waste • Other consumables (e.g. lubricants; water; chemicals) • Noise and vibration • Fugitive odour, dust, litter, liquid release • Unit operation discharge of contaminants to air/water/land • Waste characteristics associated with potential for fugitive releases are WC1, WC2, WC3, WC7, WC9 • For process discharges to the environment, all waste characteristics may be relevant but burdens associated with toxicity (WC6) and chemical reactivity (WC5) are probably the key ones NON-FLUX burdens: • Accidents

Table 6.3: Sources of Some Variable Burdens Associated with the Main Categories of Unit Operations (continued)

	VARIABLE BURDENS (related to waste throughput and/or composition)
UO5 THERMAL PROCESSES	FLUX burdens: • Electricity use • Fuel use and related emissions • Other consumables • Support fuel and consumable use per kg may be affected by scale factor of unit operation and to an extent physical form of the waste (effect on residence time required to complete thermal process) • Stack gases (gas and particulate characteristics) • Liquid (product or residue) • Solid residue effluent (Burden unlikely to cross system boundary directly unless waste burnt in the open. Effluents usually go via another unit operation (e.g. physical separation process) which will affect emission level to air/water/land) • All waste characteristics may be relevant but WC5, WC6, WC7 are most important NON-FLUX burdens: • Accidents
UO6 CHEMICAL PROCESSES	FLUX burdens: • Electricity use • Other non-reactive consumables (e.g. water demand) • Use per kg may be affected by scale factor of unit operation and to an extent physical form (affect on residence time required to complete chemical process) • Nature and amount of reaction products and hence potential to create burdens strongly dependent on input reagent/waste combination (Burden unlikely to cross system boundary directly unless waste burnt in the open. Effluents usually go via another unit operation (e.g. physical separation process) which will affect emission level to air/water/land) • All waste characteristics may be relevant but WC5, WC6, WC7 are most important NON-FLUX burdens • Accidents

Table 6.3: Sources of Some Variable Burdens Associated with the Main Categories of Unit Operations (continued)

	VARIABLE BURDENS (related to waste throughput and/or composition)
UO7 BIOLOGICAL PROCESSES	FLUX burdens: • Electricity use • Water use • Reagent or material additions to improve process or product • Potential for odour and leachate with high COD always likely and especially as many systems are open • Amount of H_2O, CO_2, CH_4, presence of trace gases and leachate characteristics depend on waste composition and specific process conditions • Quality of stabilised solids and potential to create burdens in use also dependent on input composition and process conditions NON-FLUX burdens • Accidents
UO8 STORAGE	FLUX burdens: • If the life of the container is short and the turnover of waste low, then the storage container essentially becomes a consumable item • No dependent burdens associated with fully contained storage. However release of emissions to environment is a feature of many systems and waste characteristics determine the burden. For above ground storage, releases mainly low level and resulting burden usually falls in the disamenity category (e.g. odour, litter, dust, vermin) • Waste characteristics likely to lead to releases include WC1, WC2, WC3 (particularly medium to long term). WC9 and WC7 are particularly important for landfill NON-FLUX burdens • Accidents

Table 6.4: Sources of Some Burdens Associated with the Interaction of Waste Characteristics and Unit Operations

Waste Characteristic	Road Transport UO1	Rail Transport UO2	Water Transport UO3	Physical Processes UO4	Thermal Processes UO5	Chemical Processes UO6	Biological Processes UO7	Storage UO8
Physical Form WC1	High fines content and light weight materials may create dust or litter nuisance if container body not fully closed. Liquid spills/seepage.	High fines content and light weight materials may create dust or litter nuisance if container body not fully closed. Liquid spills/seepage.	High fines content and light weight materials may create dust or litter nuisance if container body not fully closed. Liquid spills/seepage.	Many physical processes involve waste movement/agitation promoting accidental or deliberate release of material. Effective control influenced by physical characteristics. Physical form of products recovered affect benefit/value.	Efficiency of thermal processes affected by physical form but unlikely of itself, to affect type of burdens associated with thermal processing.	Efficiency of chemical processes (and hence reagent/energy use) affected by physical form but burden type unlikely to change.	Efficiency of biological processes (and hence reagent/energy use) affected by physical form. Burden type may change in composting if loss of open structure results in anaerobic activity due to reduced oxygen levels.	Physical characteristics affect likelihood of fugitive emissions during storage and rate of emission of components in the waste and breakdown products from chemical and biological activity occurring in storage
Moisture WC2	Liquid seepage for high moisture wastes. Low moisture might increase dustiness.	Liquid seepage for high moisture wastes. Low moisture might increase dustiness.	Liquid seepage for high moisture wastes. Low moisture might increase dustiness.	Low moisture may increase dustiness.	Efficiency of thermal process affected by moisture content, level but not type of burden may be affected.	Efficiency of chemical process may be effected by moisture content but burden type unlikely to change.	Low moisture inhibits biological breakdown, high moisture/free water may cause aerobic composting systems to go anaerobic by reducing oxygen access	Low moisture may increase likelihood of fugitive dust emissions. High/free moisture may increase likelihood of eachate releases.
Biodegradability WC3	Low impact in transport systems, possibility of odour nuisance	Low impact in transport systems, possibility of odour nuisance .	Low impact in transport systems, possibility of odour nuisance	Low impact other than increased odour and microbial release to air due to agitation/movement associated with physical processing.	No affect other than biodegradable waste is also combustible.	Chemical reactions associated with biodegradable organic materials may result in toxic by-products.	Full list of potential burdens associated with release of breakdown products of biological processes to, land and water needs to be considered.	Biodegradation in medium/long term storage is a major cause of potential burdens. Full list of breakdown products needs to considered.
Combustibility WC4	Unlikely to cause burdens in transport.	Unlikely to cause burdens in transport.	Unlikely to cause burdens in transport.	Unlikely to cause burdens during physical processing.	Full list of controlled emissions from thermal treatment need to be considered as potential burdens. Level of burden will depend on amounts released to the environment. Energy released a potential benefit.	Chemical reaction by products of combustible organic materials may be toxic.	No specific additional burdens likely from non degradable combustible material.	Risk of fire and associated burdens of thermal processes.
Chemical Reactivity WC5	May result in accidental release of burden on mixing with co-collected waste from other sources.	May result in accidental release of burden on mixing with co-collected waste from other sources.	May result in accidental release of burden on mixing with co-collected waste from other sources.	Potential to create burdens due to unforeseen reaction products on mixing with other waste during physical processing.	Reaction products due to heating may result in new burdens if released to the environment.	Each specific process needs to be separately assessed for reaction products. New potential burdens to all media.	May affect biological process but unlikely to be a significant property in terms of creating new burdens.	Chemical reeactions and by products may give rise to significant new burdens in prolonged storage.

Table 6.4: Sources of Some Burdens Associated with the Interaction of Waste Characteristics and Unit Operations (continued)

Waste Characteristic	Road Transport UO1	Rail Transport UO2	Water Transport UO3	Physical Processes UO4	Thermal Processes UO5	Chemical Processes UO6	Biological Processes UO7	Storage UO8
Toxicity WC6	Unlikely to result in burden unless material escapes from transport container due to seepage, spills.	Unlikely to result in burden unless material escapes from transport container due to seepage, spills.	Unlikely to result in burden unless material escapes from transport container due to seepage, spills.	If physical process leads to release of material, toxicity will influence burden type and level.	Products of thermal treatment need to be reassessed for toxicity.	All reaction products need to be assessed.	Toxic compounds may inhibit bioprocesses and effect product value and potential to create burdens in use.	Chemical and biological processes occurring during storage will affect toxicity (form and concentration).
Leachability WC7	Unlikely to result in burdens unless material accidentally released.	Unlikely to result in burdens unless material accidentally released.	Unlikely to result in burdens unless material accidentally released.	Potential burdens likely if wet physical processes employed.	Leaching characteristics change following thermal treatment.	Leaching characteristics change following chemical processes and potential to release toxic components to all media needs to be assessed.	Toxic compounds may transfer to liquid phase during bioprocessing.	Toxic compounds in the waste or created by chemical/ biological activity may transfer to liquid and/or gas phase during storage.
Sterility WC8	Unlikely to result in burdens unless material accidentally released.	Unlikely to result in burdens unless material accidentally released.	Unlikely to result in burdens unless material accidentally released.	If physical process leads to release of material or requires direct contact of human operators potential health risks occur.	Products of thermal treatment sterile.	Unlikely to be a significant property in terms of creating new burdens on chemical processing.	Bioprocesses tend to reduce pathogen content of waste but microbial activity create potential health risks (eg allergenic dusts).	Unlikely to be significant in closed storage systems but access to non sterile wastes for vermin humans may create health risks.
Volatility WC9	Transport container body should be selected to contain volatile material.	Transport container body should be selected to contain volatile material.	Transport container body should be selected to contain volatile material.	Physical processes increase likelihood of release of volatiles. Burdens will depend on chemical nature.	Products of thermal treatment non volatile at normal temperature.	Products of chemical reactions may be flammable and risks and potential burdens need to be reassessed.	Flammable gases are produced under anaerobic conditions. Risks and potential burdens need to be reassessed.	Release of flammable gases in storage system often difficult to control and contain
Flammability WC10	Design of transport container should be selected to contain such hazards.	Design of transport container should be selected to contain such hazards.	Design of transport container should be selected to contain such hazards.	Risk of explosion/fire from electrics if not spark suppressed and some processes create heat/sparks (eg shredding).	Products of thermal treatment non flammable.	Products of chemical reactions may be flammable and risks and potential burdens need to be reassessed	Flammable gases are produced under anaerobic conditions. Risks and potential burdens need to be reassessed.	Release of flammable gases in storage systems often difficult to control and contain.

Identification of waste dependent burdens

6.17 Waste dependent burdens will arise from the interaction of the wastes with the unit operations. Each characteristic (Table 5.4) that applies to the waste in question can be considered against each unit operation, to assess whether the combination is likely to lead to potential burdens (Figure 6.1). For example, the property of biodegradability (WC3) is likely to give rise to significant burdens associated with gaseous and liquid breakdown products during biological processing and during prolonged storage. Tables 6.3 and 6.4 identify the sources of many of the most common burdens associated with the interaction of waste characteristics and unit operations.

6.18 As already noted, it is important however that the potential burdens are considered within the context of the waste management option as a whole. This is because potential burdens arising in some unit operations (for example a chemical process) are unlikely to cross the system boundary directly at that point. In many cases, burdens pass as an input to another unit operation associated with pollution abatement control (for example physical separation), during which the burdens may be substantially changed or reduced prior to crossing the system boundary.

Quantification of waste dependent burdens

6.19 As noted, waste dependent burdens associated with the potential release of components or products of the waste itself are only of interest at the system boundary. Identification at unit operation level merely alerts the user that such burdens need to be considered for inventory purposes. It is not necessary, nor is it currently possible, to model fully waste management systems at the level of unit operations to predict accurately waste-related emissions or transfer of resources.

6.20 Initial data collection will normally focus on the waste management system 'boundary' rather than the full system boundary which includes the activities in the background system. The location of planned/controlled transfers of emissions and resources to the environment or the background system will be evident from the waste management activities flowsheet. Different approaches are suitable for the quantification of process and product related burdens, but both will usually require detailed information on the chemical composition of the waste input and effluent streams, and a detailed understanding of the processes themselves.

6.21 For unplanned or uncontrolled releases (for example fugitive dust, litter, liquid spills and odour), information on site location, building design, weather conditions, etc., may be required in addition to waste characteristics and unit operation data.

6.22 Appropriate data collection methods will vary on a case-by-case basis. However the common aim is to quantify waste related burdens to enable energy, mass and material balance for the system to be drawn up.

6.23 Thus a range of approaches and data sources will be used to quantify waste dependent burdens and it is vital that the procedures used for each study are well documented. The steps and data sources that may be used are summarised below:

- identify from the flowsheet those unit operations where planned releases of waste or products from waste into the environment or the background system occur;
- identify from the flowsheet those unit operations which require resources from the environment or the background system;
- in the context of the study Goal, and the burden types identified, determine which burdens require quantification for the inventory (this may be an iterative process requiring some preliminary assessment of burden levels to determine significance);
- for existing systems use measured/monitored values where possible, for example, emission inventory data, product sales, resource purchasing data;
- where measured values for the system are unavailable, use data from similar systems or legislative limit data;
- for product related burdens where levels can be related to specific inputs, detailed waste composition data and process models can be used to calculate burden levels;
- for process related burdens monitored data, legislative limits and performance specifications are the main sources of information;
- burdens which are 'unplanned' but are known to be associated with waste management activities, for example, burdens resulting from an explosion, may be better dealt with outside the LCI procedure (for

example using the planning process), particularly in the case of rare occurrences. However, the potential impact should not be assumed to be insignificant (for example waste tyre dump fire);

- for emissions and resources that transfer between the waste management system and the environment directly, the burdens should be recorded relative to the appropriate functional unit; and,

- for resources and products that transfer between the waste management activities and the background system, record values and consult relevant industry sectors to establish the life cycle impact of these activities on the environment. For waste derived products it will be necessary to ensure that the waste management activities include all the processes required to deliver a 'product' that can substitute for normal inputs the industry. This will enable the avoided burden approach discussed in Chapter 5 and below to be followed.

Identification and quantification of avoided burdens

6.24 Avoided burdens are realised when the waste management activities eliminate or reduce activities in the background system. The most obvious way this occurs is with materials or energy recovery and the materials and energy balance will provide the quantities needed to calculate the avoided burdens.

6.25 As noted above, the appropriate stage for considering avoided burdens is when the waste derived product can be introduced into the background system as a direct substitute for an existing product. Data are then required for the 'cradle-to-gate' burdens associated with producing the conventional product. The waste management system is credited with these as 'avoided burdens'. Where the contribution of product is small in comparison with the conventional consumption, for example, electricity contributions to the national grid, no iteration is required to take into account the effect of including the 'new' product in the life cycle of the conventional product. But if the waste system under consideration makes a major contribution to provision of the 'product' it will be necessary to consider the interaction between life cycles if the avoided burden levels are significant in terms of the study goals. An extreme case would be where no substitute 'product' can be identified and use of the 'product' has to be assessed back to the environment boundary. Examples of this could be low grade waste composts used for land reclamation or the fact that the product of landfilling waste is 'new' land, but does not fall into any obvious conventional classification of land.

The Allocation of Environmental Burdens

Allocation of waste independent burdens

6.26 If the waste under consideration shares common facilities with other waste arisings, or information is required on only part of a given waste type, a method to allocate burdens quantified for the system as a whole is required.

6.27 The degree of subdivision of the waste management system into separate activities will determine the precision to which allocation can be carried out. It is unlikely that many users will require assessment at the unit operation stage. For most purposes disaggregation of the system is likely to be required when there is a significant change in the nature of the waste, when new wastes are added or when the wastes are separated into different streams. If a single facility involves a number of such changes, for example, an incinerator plant, this may require operations within the facility to be considered separately. Using the unit operation approach for identification and quantification of waste independent burdens enables this step to be carried out. As the burden levels allocated to the component of interest will vary at different levels of disaggregation, the procedures adopted must be reported in detail.

6.28 Allocation of waste independent burdens should be on the basis of weight throughput of the component of interest at the input stage of a facility, unit operation or cluster of unit operations. Although allocation on the basis of volume could be argued for some unit operations, for example, storage operations, the volume contribution of a particular component in a mixture of solid waste is difficult to assess, will vary on compaction and is dependent on factors such as size distribution, shape and flexibility of both the component *and* the remaining mix. Thus it is not possible to allocate a value to a component based on knowledge of the component alone. Furthermore, use of both weight and volume for allocation within the same system will require detailed explanation and it would be difficult to formulate common rules to ensure studies were comparable.

6.29 Where a process changes the weight and/or composition of the waste, knowledge of the weight contribution made to the process outputs by the component of interest should be used to allocate burdens in subsequent processes. Thus, for the calculated burdens for the ash transport stage following incineration, allocation of the waste independent burdens would be based on the proportion of ash contributed by the component of interest.

6.30 Ideally, the allocation procedure used should be consistently applied to all waste independent burdens considered, i.e., fixed, variable, flux or non-flux burdens. Where this is not practical or considered unnecessarily precise for burdens of low significance, variation of method should be stated (in practice this will probably relate to the degree of disaggregation considered, for example, a burden such as visual intrusion may be allocated on the basis of weight input contribution at the facility level whereas capital resource demand may be considered at the unit operation level).

Allocation of waste dependent burdens

6.31 For certain studies it may be desirable to relate the likely burdens generated at particular points in the waste management system to specific components of the waste being processed. For example, if one of the goals of the study is to reduce the heavy metal burden(s) resulting from an existing waste management system, then knowledge about which components of the waste contain heavy metals and at which point(s) in the system the metals are released to cross the system boundary, would be essential. Conversely, and especially for waste management systems which are planned but do not yet exist, it may be impossible to identify all of the potential burdens expected without considering the characteristics of individual waste components.

6.32 The starting point for allocating burdens to specific components of heterogeneous mixtures such as household waste is a detailed consideration of the characteristics of the waste. As noted, the list of characteristics for a mixed waste such as household waste is likely to include all those identified in Table 5.4. This does not provide a sufficiently discriminating tool for burden identification to the level of specific waste components.

The Components of Household Waste

6.33 Analysis of household waste normally involves hand-sorting the waste into 11 separate component categories, but data at more detailed levels are also available (for example the 33 categories used in the NHWAP[1] and the detailed categories used to define packaging waste by ERRA[2]). Identifying the characteristics of each component category greatly facilitates the

1 National Household Waste Analysis Project
2 European Recovery and Recycling Association

identification of waste dependent burdens and the allocation of those burdens to specific waste components.

Table 6.5: Allocation of Waste Characteristics to Waste Components

Household Waste Category	Approximate Distribution % wt	Characteristic Allocated and Indication of Significance Level		
		High	Medium	Low
Fe Beverage Cans	30			WC2, WC8
Fe Food Cans	50		WC3, WC8	WC1, WC2, WC6, WC4
Fe Other Cans	5		WC1, WC6, WC9, WC10	WC2, WC5
Fe Batteries	5	WC6	WC5	WC7
Fe Miscellaneous	10		WC1	WC6, WC8
Fe Category Total	100		WC3, WC6, WC8	WC1, WC2, WC4, WC5, WC7, WC9, WC10

6.34 For example, Table 6.5 provides a list of sub-categories identified within the main ferrous metal category of household waste and their respective percentage weights, i.e. ferrous beverage cans contribute approximately 30% by weight of the total ferrous category. For each sub-category, the waste characteristics from Table 5.4 which apply have been identified and ranked as being present at 'high', 'medium' or 'low' level.

6.35 Thus for beverage cans, moisture (WC2) and sterility (WC8) are characteristics identified as being present at 'low' level reflecting the fact that these cans will contain some drink which may leak or spill and the cans will consequently not be completely sterile. Food cans, conversely, tend to be more highly contaminated with putrescible waste leading to biodegradability and sterility characteristics (WC3, WC8) at 'medium' level. These cans are also assigned a 'low' level for jagged edges from can opening (WC1), moisture (WC2), toxicity (WC6) from lead content in soldered seams and combustibility (WC4) from food residues and paper labels.

6.36 Paint, solvent and aerosol cans are included in the 'other cans' category, thus increasing the ranking in this category for toxicity and bringing volatility (WC9) and flammability (WC10) characteristics into the frame. Potential for pressurised containers to present an explosion risk is represented by WC1 at the 'medium' level. Notable characteristics for the other ferrous sub-categories include 'high' toxicity and 'medium' chemical reactivity levels for batteries.

6.37 The characteristics for the ferrous waste category as a whole might then be derived from the individual rankings and proportions of each sub-category present. This could be done on a semi-quantitative basis (a combination of sub-category percent and characteristic level expressed as a number, for example, 3, 2, 1, instead of 'high' 'medium', 'low'). In the example given here, no such formula has been adopted, but for the ferrous category as a whole, WC3, WC6, WC8 are considered to be present at 'medium' levels and all the other characteristics present at only a 'low' level.

6.38 The same procedure can then be repeated for other sub-categories and finally the characteristics of the waste as a whole can be assessed from the results for the 11 main categories of components. Examples for the main categories are shown in Table 6.6, together with the assessment for a typical household refuse mixture. From this table, characteristics present in the refuse mixture at a 'high' level include combustibility and biodegradability. Characteristics present at a 'medium' level include physical form (covering sharps, pressurised containers, litter and dust), moisture content (potential for liquid release) and sterility (presence of pathogens). Household refuse exhibits the remaining characteristics of chemical reactivity, toxicity, leachability, volatility and flammability, at a 'low' level.

6.39 In summary, waste dependent burdens arise as a result of interactions occurring when wastes with specific characteristics flow through the unit operations of which a waste management system is comprised. Burdens are characterised by taking each of the generic unit operations in turn, identifying the generic characteristics of the waste passing through that operation, and then assessing whether burdens are potentially created at that point in the waste management system. Burdens which are critical in terms of the goal of the study may be traced back to the waste characteristic contributing to that burden and thence to the specific waste component responsible for the expression of that characteristic.

Table 6.6: Allocation of Waste Characteristics to Waste Categories

Household Waste Category	Approximate Distribution % wt	Characteristic Allocated and Indication of Significance Level		
		High	Medium	Low
Paper	30	WC4	WC3	WC1, WC8
Plastic Film	5	WC4	WC1	WC3, WC8
Rigid Plastics	5	WC4		WC2, WC3, WC8
Textiles	3	WC4	WC3	
Misc. Combustibles	5	WC3, WC4, WC8		WC2, WC6, WC7
Misc. Non Combustibles	5			WC6, WC7
Putrescibles	25	WC2, WC3, WC8	WC4	WC7
Glass	8		WC1, WC3, WC8	W2
Ferrous Metal	6		WC3, WC6, WC8	WC1, WC2, WC5, WC7, WC9, WC10
Non Ferrous Metals	1		WC3, WC6, WC8	WC2, WC5, WC7
-10mm Fines	7	WC2, WC3, WC8	WC1, WC6	WC7
Total	**100**	**WC3, WC4**	**WC1, WC2, WC8**	**WC5, WC6, WC7, WC9, WC10**

Guidelines for Compiling Life Cycle Inventories for Waste Management 7

Introduction

7.1 In this Chapter the recommended guidelines for compiling a life cycle inventory for waste management options are summarised and further guidance is given on the treatment of specific waste management activities.

7.2 The four stages of carrying out an LCA are:

1. **Goal Definition and Scoping,** which defines the system to be studied and the functional unit on which the study is to be based;
2. **Inventory Analysis,** which compiles data on resources used and wastes and emissions generated in the form of an inventory table;
3. **Impact Assessment**, which converts the inventory table into a number of quantified environmental impacts; and,
4. **Interpretation**, where the inventory and impact assessment results are assessed in line with the goal and scope of the study.

The guidelines presented below for the LCI of waste management cover the first two of these stages.

7.3 It is also important to recognise that further work is required in software development to allow easy application of the guidelines as they currently stand. Software will be helpful in providing data on potential burdens, and probably essential in manipulating the large number of data values likely to be involved for any practical waste management option.

LCI Guidelines for Waste Management

1) *Goal definition and scoping*

i) **Purpose**. Write down a clear and unambiguous statement of the reason for carrying out the LCI and the intended use of the results. State whether the results will be used internally or externally, for example, to influence waste management planning decisions or policy.

Recommendations
The objectives and the final users of the study must be clearly and unambiguously defined.

ii) **Scenarios.** When comparing alternative waste management options, describe and document these as comparative scenarios. The scenarios so defined will become the object of the Inventory Analysis.

Recommendations
The inclusion or exclusion of alternative scenarios in a comparative study must be justified.

iii) **Critical review.** Decide whether or not the study requires critical review. If so the critical reviewer or panel should be chosen and involved in the scoping exercise.

Critical review is recommended for all studies.

Consideration of the involvement of stakeholders should be made where appropriate.

iv) **Additional expertise.** Decide on the need for any additional expertise in the project team.

Additional expert knowledge should be involved in the project team where appropriate.

v) **Functional unit.** Clearly explain the function of the system(s) being studied. Define the functional unit which will be used as the reference point for all inventory data and as the unit of comparison. The precise functional unit will depend on the goal and scope of the study. It will normally be mass of waste of specified composition or origin.

The choice of functional unit must be justified in relation to the goal of the study.

The functional unit must provide the basis for comparison within a comparative study, i.e. it must be the same for all comparisons.

For waste management applications the functional unit must be related to units of mass and not the volume of the waste.

vi) **Initial system boundaries.** Define the initial system boundaries by drawing a simple flow diagram. This should include the principal waste management activities of interest and any linked activities required for the production of ancillary materials.

Where alternative scenarios are being compared, operations specific to one or the other scenario are identified to define the basic distinctions between the alternatives. Common processes and operations which contribute to the alternative scenarios in exactly the same way and to the same extent can then be identified and not considered further in the comparison.

The system boundaries must be defined such that, as far as is possible, the function(s) of the systems to be compared are the same.

Where differences in system boundaries between comparative scenarios are unavoidable, these must be justified.

Any distinction made between the operations to be considered for the waste management activities and the background system, must be clearly reasoned and explained.

vii) **Environmental burdens.** A preliminary identification of the potential environmental burdens arising from waste management activities and processes in the background system should be made. Taking account of the Goal of the study and whether or not other tools such as EIA or risk assessment will also be used, it may then be decided to exclude certain burdens from the Inventory Table. Any burdens which are to be excluded from subsequent analysis must be listed and their exclusion justified, for example, by demonstrating via sensitivity analysis that the outcome of the study will not be significantly affected.

In general, burdens associated with the production of capital goods used in the waste management activities will be included, but those associated with the production of capital goods in the background system are not.

Recommendations
The burdens considered must relate to the goal of the study and particularly to any decisions to be based on the results.

Consideration must be made of any other tools to be used in the decision making process.

All burdens must be recorded in the inventory. The exclusion of burdens must be noted and their exclusion explicitly justified in the report.

Assumptions of flows displaced by materials leaving the waste management activities must be fully justified.

Any material or energy flows across the system boundary must be clearly defined and mentioned in the report.

viii) **Data quality.** The types and sources of data to be used in the study should be determined and recorded. The data used should relate to the goal of the study and the scenarios chosen for comparison. For example, in a local study the data used should be specific to local conditions. Where a study makes more generalised recommendations, for example, in relation to national policy, then average data are preferred.

Changes in materials and energy demand resulting from the waste management system must be evaluated by their marginal effect on the relevant supply in the background system. Where marginal data are not available the data should refer to current best practice for which data are accessible.

Careful consideration should be given to the appropriateness of a particular data source in relation to the study.

The choice of specific, average and marginal data should depend on the goal of the study and the scenarios being compared.

2) *Inventory analysis*

ix) **Detailed definition of the system.** Refine the initial system boundary. Draw a flow diagram of all the main process steps, including transport, comprising the waste management activities under study. Number each of the principal processes identified. For each numbered process, draw a more detailed flow diagram identifying the operations making up this process step. Indicate on this flow diagram the corresponding generic unit operations from the list of 45 provided (see Table 5.1 and Figure 7.4).

Taking account of the decisions taken during the Goal and Scoping stage (e.g. point vii), record the relevant capital and consumable items used by the waste management activities covered in the flow diagrams. From this, write down which activities should be included within the system boundaries.

Recommendations

The level of detail at which activities within the system boundary are described must be defined in relation to the Goal of the study.

Use generic unit operations to describe the waste management activities taking place within the system boundary.

x) **Compilation of the Inventory Table.** Taking as a starting point the detailed process flow diagrams developed in ix), identify which burdens are waste independent, using the guidance given in Tables 5.6 and 5.7.

Describe the wastes being handled by the system in terms of the standard waste characteristics given in Table 5.3. Consider the potential interaction of the waste characteristics identified with the unit operations shown in the process flow diagrams. Use the guidance given in Table 5.5 and 5.6 to consider which are the waste dependent burdens.

Make the range of environmental burdens included in the Inventory Table as comprehensive as possible.

The data in the Inventory Table should be restricted to materials and energy flows, but 'non-flux' burdens must be recorded elsewhere.

Data collection. Having broken down the waste management activities into component unit operations and identified the waste independent and waste dependent burdens, the relevant data must be gathered. It may also be necessary to obtain much more detailed information on the throughput and composition of the wastes undergoing the unit operations (for example, calorific value, chemical analysis, biodegradable content, etc.).

Relevant data bases can be identified and further effort can be focused on those unit operations for which little information currently exists and the burdens associated with the waste characteristics.

Calculation. All data collected must be fully documented. Flow data collected needs to be expressed in terms of a reference flow (e.g. 0.35kg of burden/kg of separated waste). Compilation into the Inventory Table involves relating these to the functional unit of the system. Where it is necessary to apply a method to allocate burdens between, co-products, co-inputs or outputs, this should be done wherever possible on the basis of physical causality. For example, cadmium emissions from MSW incineration should obviously be allocated to the cadmium-containing items in the waste.

Recommendations
All data must be fully documented and assumptions detailed.

Process data should ideally mass balance. Discrepancies should be viewed as potential data gaps.

The data must be compiled in such a way as to allow disaggregation for further analysis.

Allocation of burdens should be done wherever possible on the basis of physical causality.

xi) **Sensitivity analysis.** Sensitivity analysis is a key feature of LCI.

All assumptions and allocation choices and areas of data uncertainty should be tested by sensitivity analysis as an integral part of the study.

xii) **Reporting** The study should be reported in a manner which provides adequate transparency of methodology and data in relation to the goal and scope of the study.

The report must cover:

- the goal of the study, including the intended application
- the scope of the study including decisions on critical, review, functional unit, choice of scenarios, system boundaries, burdens considered, data quality and assumptions.

Results should be presented graphically wherever possible.

Treatment of Specific Waste Management Options

7.4 To supplement the guidelines given above, the following notes provide more specific advice relating to important waste management options.

1) *Treatment of MSW inçineration*

i) **Energy**. An incinerator may both use and produce grid electricity. As with other energy using processes, the production of the energy used should be included within the system boundary. The treatment of energy production should include burdens arising from extraction and processing of primary fossil fuels as well as from power generation and distribution.

The type of data selected for electricity inputs is critical, because the associated environmental burdens depend on the mix of sources from which energy is derived and the conversion technologies used. It has been advocated (Udo de Haes *et al.*, 1994) that burdens should be based on the European average fuel mix. However, this is not appropriate for the UK whose electricity supply system exists almost in isolation from Europe and especially where the effect of changes in waste management strategy on national energy supply are being investigated.

Plants using waste as a fuel for electricity generation normally operate on a 24-hour constant output basis. Therefore the emissions avoided by recovering energy from waste are best assessed as the marginal change in base-load electricity generation. The avoided emissions should be evaluated for the capacity which will actually be displaced, rather than any environmental or economic optimum; in the UK this is likely to be coal-fired generating capacity.

Recommendations
When justified by the goal of the study it is recommended that a study be carried out to determine the burdens avoided by marginal changes in electrical base-load output.

If this cannot be done then the assessment should be based on either the UK average fuel mix or coal-fired generation. The effect of alternatives should then be considered during the sensitivity analysis stage.

Where energy is recovered as process energy or used for space heating, the avoided burdens should be based on the actual fuel displaced, and must include the burdens due to extracting and processing the fuel.

2) ***Treatment of landfill***

Landfill sites taking biodegradable wastes may generate energy from landfill gas and thus the energy issues discussed in relation to incineration are also relevant. Landfill sites also have similar problems to incinerators with regard to the allocation of burdens, except that there is difficulty in deciding the time period over which emissions should be considered. A logical possibility is to consider burdens at two time intervals, 50-100 years and geological time.

Recommendations

Waste-dependent burdens should be allocated on the basis of the composition of the wastes flowing through the process.

Conduct a sensitivity analysis on the choice of time-scale over which burdens are assessed.

3) ***Treatment of recycling and composting***

Materials recovered from waste may need further reprocessing before any credit can be given against materials displaced. In these cases the reprocessing operations may need to be included with the waste management activities within the system boundaries.

In some cases it may be difficult to demonstrate that a recycled material directly replaces another material. For example, recycled plastic does not always replace virgin plastic, or the replacement may not be in the ratio 1:1.

If the avoided production is overseas, then it will use local energy production and the wastes produced will be dealt with using local waste management practices. Deviation from functional equivalence in this way should be investigated using sensitivity analysis.

Allocation of avoided burdens must be done on the basis of functional equivalence.

Additional processes required to achieve functional equivalence should be included within the system boundary if this appropriate in relation to the goal of the study and the other scenarios being considered.

Any deviation from full functional equivalence should be investigated during the sensitivity analysis stage.

4) *Treatment of reuse and waste minimisation*

If the system boundary is drawn at the curtilage of the premises involved then this might exclude household activities concerned with waste minimisation and reuse from consideration. But these activities do give rise to environmental burdens such as washings from recyclable food cans and the operation of sink waste disposal units. These effects might be accounted for by changes in the quantity and composition of household waste being handled by the system, or by simply bringing these activities inside the system boundary.

Illustrative Example   8

Introduction

8.1 The recommended guidelines for compiling a life cycle inventory for waste management are illustrated below by working through an imaginary, but realistic, example. Key points within the guidelines are highlighted, focusing on goal definition and scoping and the description of the waste management activities using generic unit operations and waste characteristics. The range of environmental burdens involved is discussed, but quantification of burdens has not been attempted. Detailed burden identification and quantification would require an extensive data bank to provide the level of detailed information needed.

8.2 The illustrative example concerns a waste management operation which is undertaking a strategic review of its waste disposal capacity. The organisation disposes of approximately 350,000 tonnes per annum of non-hazardous wastes generated from a particular geographical area. All of the waste arisings are currently disposed of to a single landfill, with an expected remaining life of 25 years. In view of the long lead times necessary to obtain planning permission for new disposal capacity the company is now actively considering options for the future. As an alternative to current practice one possibility is to extend the existing landfill life, by incinerating a substantial proportion of waste which is currently landfilled. This would be achieved by building a new incinerator, with energy recovery, on the site of the present transfer station.

8.3 In tandem with an economic and operational appraisal the company wishes to examine the environmental burdens which may be associated with this option. An important question for any future planning process will be whether the proposed development will impose any additional environmental burdens compared with existing arrangements. To help answer this question the company has decided to undertake an LCI of the current management option and of the proposed development.

8.4 It must be emphasised that this example is given purely as an illustration of how the principles established in this report might be applied. For reasons of brevity and clarity, some practical implications of the scenarios chosen have been deliberately ignored.

Goal Definition

(i) Purpose

8.5 The purpose of the study is to compare the environmental burdens associated with two alternative strategies for the future management of the non-hazardous waste arisings from the designated geographical area.

8.6 The results of the study will be used for two purposes. In the first instance the analysis will be used to inform the organisation's internal strategic planning decisions. Together with an economic and operational appraisal, the results will be used to decide which strategy the company should adopt and promote through the statutory planning process. Subsequently, it is envisaged that the results will be used to support any planning applications that the company may make by providing data to the Environment Agency and to members of the local community, and by informing the statutory Environmental Impact Assessment which is likely to be required.

(ii) Scenarios

8.7 The scenarios which describe the two options being considered and upon which the analysis will be based are outlined in Table 8.1. More detailed information about the Existing and Proposed Scenarios is given later in this Chapter to illustrate how the method of describing waste management activities is applied.

(iii) Critical review

8.8 In view of the high level of public interest that the company's proposals are likely to arouse, and the external scrutiny inherent in making a planning application, it is considered essential that the project should have the benefit of external critical review from an early stage. Three independent experts with international reputations in the fields of LCA, environmental planning and waste management have therefore been invited to form a critical review panel. The remit of the review panel will be to provide advice at the planning stage of the project and to formally review all key conclusions and decisions based on the results of the study.

Table 8.1: Outline Description of Existing and Proposed Scenarios

EXISTING SCENARIO	k tonnes
1) Kerbside collection of approx. 90% of household wastes in plastic bags for disposal to landfill via a transfer station.	(100)
2) Co-collection of approx. 15% of commercial and industrial wastes with 1) for disposal to landfill via a transfer station.	(20)
3) Collection of approx. 10% of household wastes at a CA site for disposal to landfill (direct transport).	(10)
4) Separate collection of approx. 85% of commercial and industrial wastes for disposal to landfill (direct transport).	(120)
5) Separate collection of 100% of construction and demolition wastes for disposal to landfill (direct transport).	(100)
Total waste inputs per annum350 k tonnes	

PROPOSED SCENARIO	k tonnes
1) Kerbside collection of approx. 90% of household wastes in plastic bags for mass burn incineration. Disposal of ash to existing landfill.	(100)
2) Co-collection of approx. 15% of commercial and industrial wastes with 1) for mass burn incineration. Disposal of ash to existing landfill.	(20)
3) Collection of approx. 10% of household wastes at a CA site for disposal to landfill (direct transport).	(10)
4) Separate collection of approx. 85% of commercial and industrial wastes for disposal to landfill (direct transport).	(120)
5) Separate collection of 100% of construction and demolition wastes for disposal to landfill (direct transport).	(100)
Total waste inputs per annum350 k tonnes	

(iv) Additional expertise

8.9 The company has a wide range of technical expertise available in-house, covering most of the key areas likely to be involved. However, close liaison with the engineering company offering the preferred incinerator plant design (to be provided on a turn-key contract) will be required. In addition independent verification of predictions of incinerator stack emissions will be required and it is assumed that this will be part of the statutory EIA undertaken by independent consultants.

(v) Functional unit

8.10 The function of the system is to manage the MSW (i.e. non-hazardous household and similar commercial/industrial wastes) and construction/demolition wastes arising in the defined geographical area. It is assumed for the purposes of this example that the quantity and type of waste arisings in this area will stay constant over the next 20 years. The functional unit is therefore:

'a tonne of non-hazardous waste, of current composition, arising from the defined geographical area'.

(vi) Initial system boundaries

8.11 The principal waste management activities of interest in the Existing Scenario and the Proposed Scenario are shown in the simple flow diagrams overleaf (Figures 8.1 and 8.2). These diagrams reveal that the comparative scenarios have a number of processes in common. These are:

1. the delivery by householders of approx. 10% of wastes to a CA site;
2. the CA site operation;
3. the separate collection of approximately 85% of commercial and industrial wastes for direct transport to landfill; and,
4. the separate collection of 100% of construction and demolition wastes for direct transport to landfill.

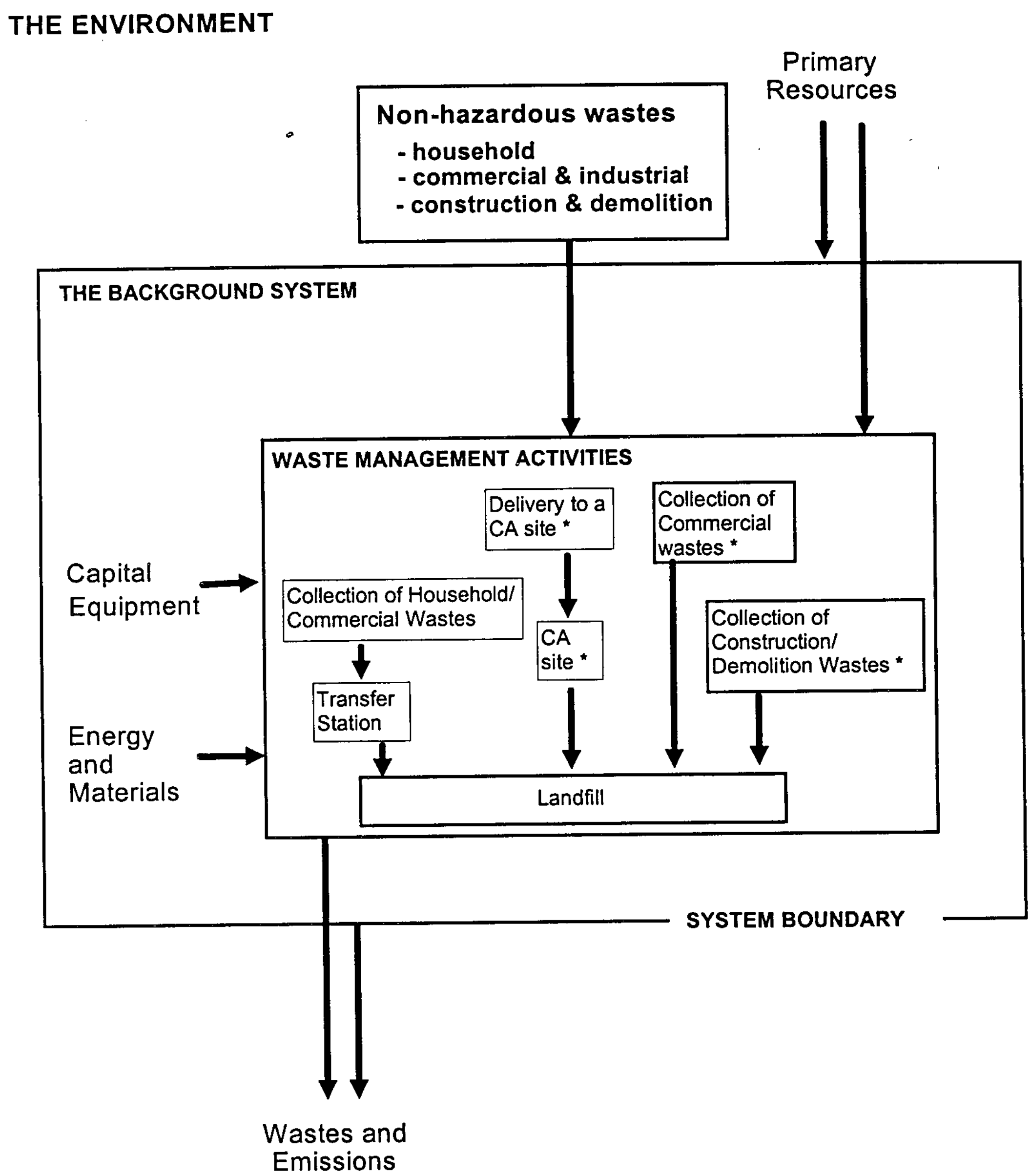
It may be assumed that these processes contribute to the alternative options in exactly the same way, and to the same extent, and there is therefore a strong case that they should not be considered further in the comparison. Nevertheless, for the purposes of the present illustration, all of these processes have been retained in the analysis which follows.

(vii) Environmental burdens

8.12 The preliminary consideration of the environmental burdens has identified a number of key areas of concern.

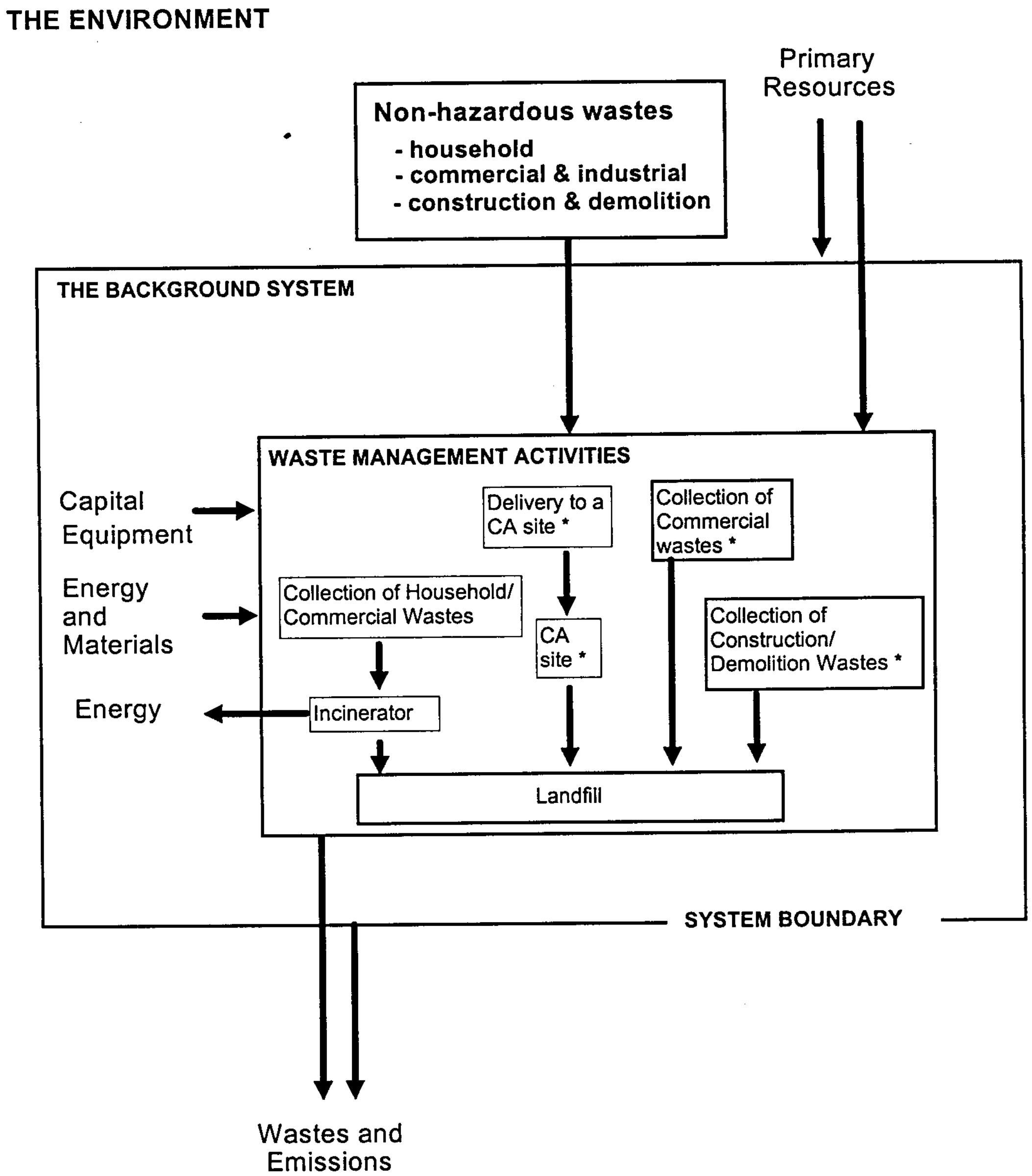
Capital equipment. The incineration option would require the supply of substantial new plant and equipment and therefore the analysis should include the environmental burdens associated with the production of capital equipment. In addition to the incinerator plant, this should include the production of all vehicles involved in the two options.

Figure 8.1: Initial System Boundary for Existing Scenario



* Denotes processes which are common between the two scenarios.

Figure 8.2: Initial System Boundary for Proposed Scenario



* Denotes processes which are common between the two scenarios.

Because the landfill space is already in existence, it might be argued that burdens associated with the production of capital items, for example, the landfill liner, leachate treatment and gas flaring systems, will be common between the two scenarios and need not be considered. However, it is possible that some additional landfill capacity will be required in one or both of the scenarios during the period in question. A scoping study using generic data will therefore be carried out to ascertain the likely burdens associated with this type of capital equipment. Only if this shows that burdens are likely to be significant will a more detailed and specific study be made.

Construction and decommissioning. Construction-related burdens associated with demolishing the existing transfer station and building an incinerator on the site, for example noise, dust and traffic congestion, will cause public concern. These and similar burdens which will arise from plant decommissioning in the future must therefore be addressed, although it is anticipated that this aspect will be dealt with by the EIA, rather than this LCI study.

Consumable items. The range of consumable items whose production will be included in the system boundary has provisionally been set to include:

- mains electricity;
- mains water;
- petroleum spirit;
- diesel;
- lubricants;
- vehicle tyres and batteries;
- calcium hydroxide (for incinerator gas scrubbers); and,
- water treatment chemicals (for incinerator boiler water treatment).

'Non-flux' burdens. On the evidence of past experience, disamenity burdens (visual intrusion, noise, congestion, litter, debris etc.) will become central issues in any future planning application. Following current LCA practice, these burdens will not be included in the quantitative Inventory Table. It is essential, however, that burdens of this type are comprehensively identified and recorded as a footnote to the Inventory Table, and that steps are taken to assess the resulting impacts either through the statutory EIA process or some other mechanism.

(viii) Data Quality

8.13 Avoided emissions, which will be credited to the Proposed Scenario in respect of energy exported, are likely to be very significant to the outcome of the study. Priority will therefore be given to obtaining data on the effect of the incinerator on the energy generating system. This should be as locally relevant as possible, ideally taking into account any changes expected over the anticipated lifetime of the incinerator.

8.14 The burdens from degradation of wastes in the landfill will also be critical. For the Existing Scenario, because the facility is an existing one, the data will be site-specific, i.e. collected from the site over an extended period. When considering the Proposed Scenario, the effect of the disposal of large volumes of ash on emissions of landfill gas and leachate generation will also need to be estimated.

8.15 The data used for the production of materials consumed by waste management activities within the system will be based on the average of current best practice.

Inventory Analysis

8.16 The additional descriptive detail required to work through both the Existing and Proposed Scenarios is given in the notes in the boxes below.

(ix) Detailed definition of the systems

8.17 Notes on the definition of the Existing and Proposed Scenarios are given in Tables 8.2 and 8.3. Detailed flow diagrams (based on Figures 8.1 and 8.2) which represent all the transport and operational activities included in the waste management activities in both the Existing and Proposed Scenarios, have been developed. These identify, for the Existing Scenario, 9 discrete transport and other activities, and, for the Proposed Scenario, 10 discrete activities. These all require more detailed description (Figures 8.3 and 8.4). Each of the numbered activities shown in Figures 8.3 and 8.4 has been further disaggregated and is represented, using the generic unit operations, in the detailed flow diagrams compiled for both Scenarios (Figures 8.5 and 8.6).

Table 8.2: Description of Existing Scenario

The area concerned is outer suburban.

Approximately 3% of household wastes are currently diverted from landfill via recycling banks. This has been ignored for the purposes of this illustrative example.

Kerbside collection of household wastes. Black plastic bags are provided by the collection company. Weekly collection by RCV from the kerbside. Approx. 25% of carriage is commercial and industrial wastes.

Separate collection of commercial/industrial wastes. Collection made by a combination of FELs, RELs and skip loaders at approx. weekly intervals.

Civic Amenity site. Householders transport bulky items of waste to the CA site using private motor vehicles. At the site waste items are deposited in a walk-in ISO roll-on/roll-off container. The bulked waste is then transported to the landfill by lorry.

Transfer Station. Waste from RCVs is dumped in a bunker and loaded by front bucket loader into 20 tonne capacity articulated bulk freighters for onward transport to the landfill site. The round trip is 30 miles.

Collection of construction and demolition wastes. Wastes are transported direct from the construction sites to the landfill sites using a variety of high-sided trucks.

Landfill site. The landfill uses dozer-shovels to move waste into cells and to spread cover material. Waste is compacted by steel-wheel compactors before covering.

The landfill is lined and has a leachate collection and treatment system. The treated leachate is discharged to sewer and therefore requires initial treatment only. This consists of an aerating batch reactor. An electric pump collects leachate from the site drainage system and delivers it to the treatment pond. Electrically-driven turbines aerate the liquor in the pond and are switched off at intervals, allowing the sludge to settle. Settled sludge is drawn off from the bottom of the pond by gravity to a sump. The sump is emptied by a suction tanker and the sludge deposited in a landfill cell. The treated effluent (supernatant) is drained by gravity to sewer.

There is a landfill gas collection and flaring system. Gas is drawn from a series of vertical wells by an electric fan and passed to a single flare stack where it is burnt. The flare stack is fitted with an electric/propane starter and a flame arrester. There are no facilities for energy recovery.

8.18 The Waste Management Activities within the Existing Scenario have thus been expressed as a combination of 33 unit operations, using 16 of the 45 generic types which are available from Table 5.1. In the Proposed Scenario 56 unit operations are used.

Figure 8.3: Waste Management Activities in Existing Scenario

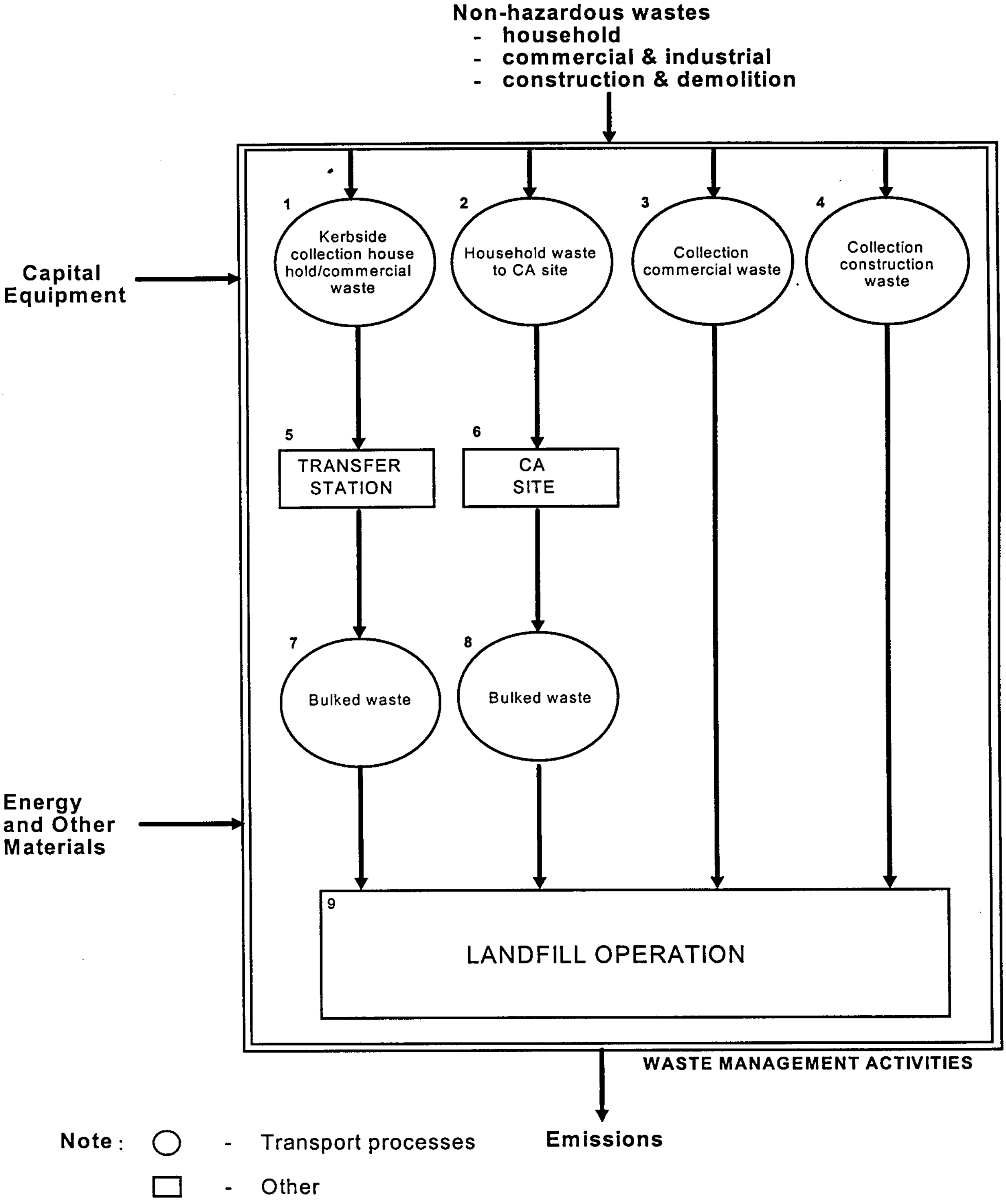
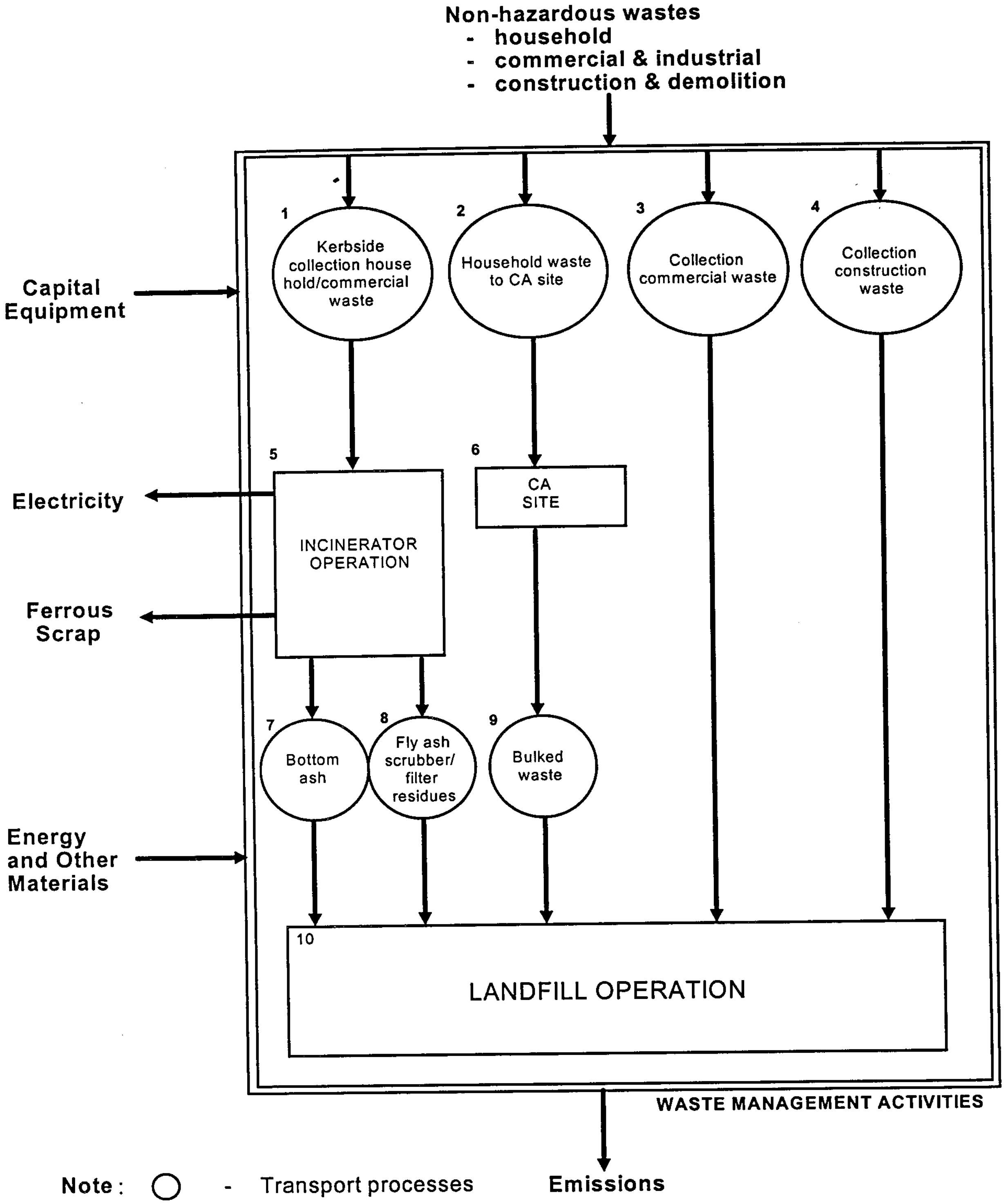


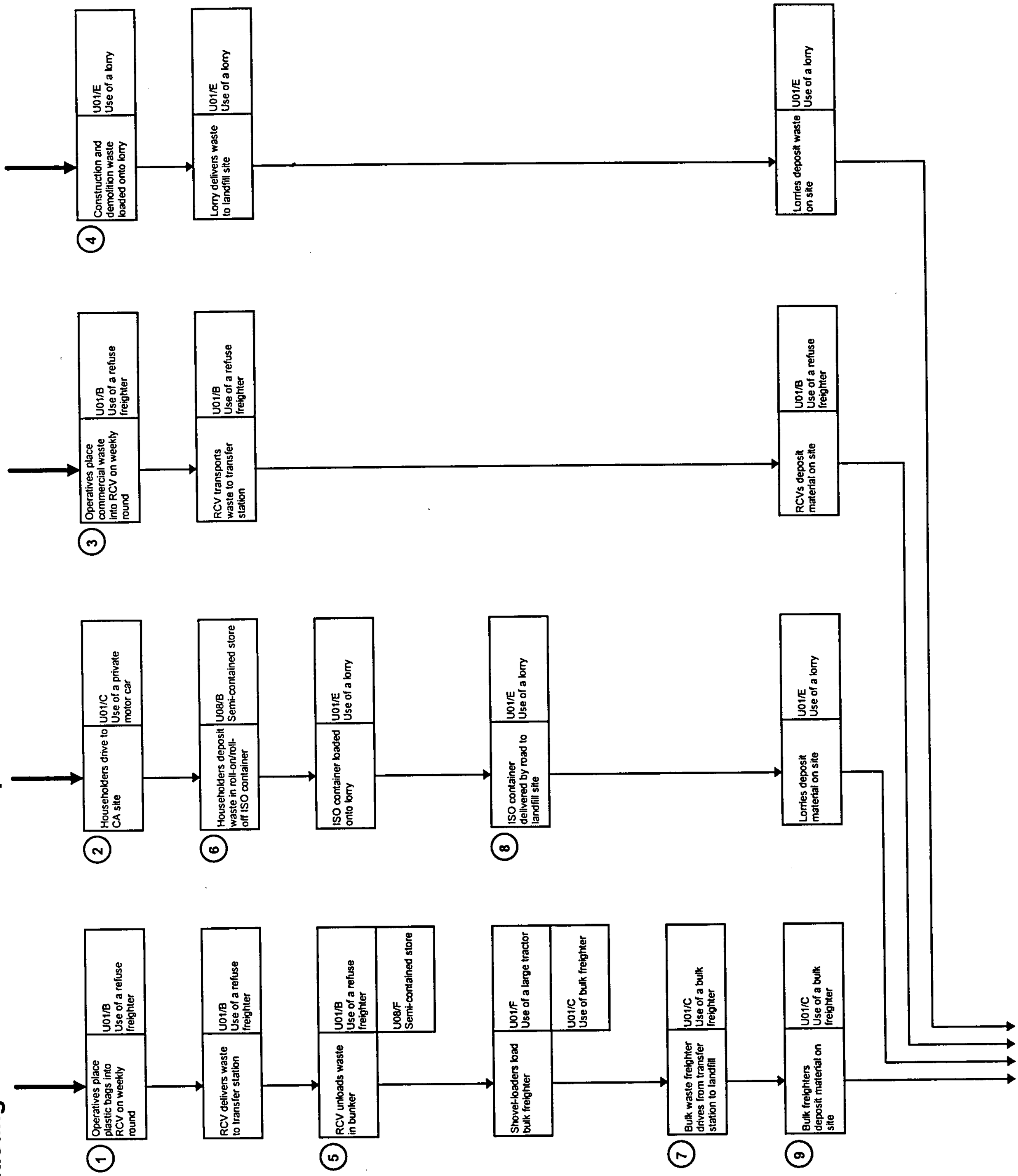
Figure 8.4: Waste Management Activities in Proposed Scenario



Note: ○ - Transport processes

□ - Other processes

Figure 8.5: Existing Scenario - Process Description and Unit Operations



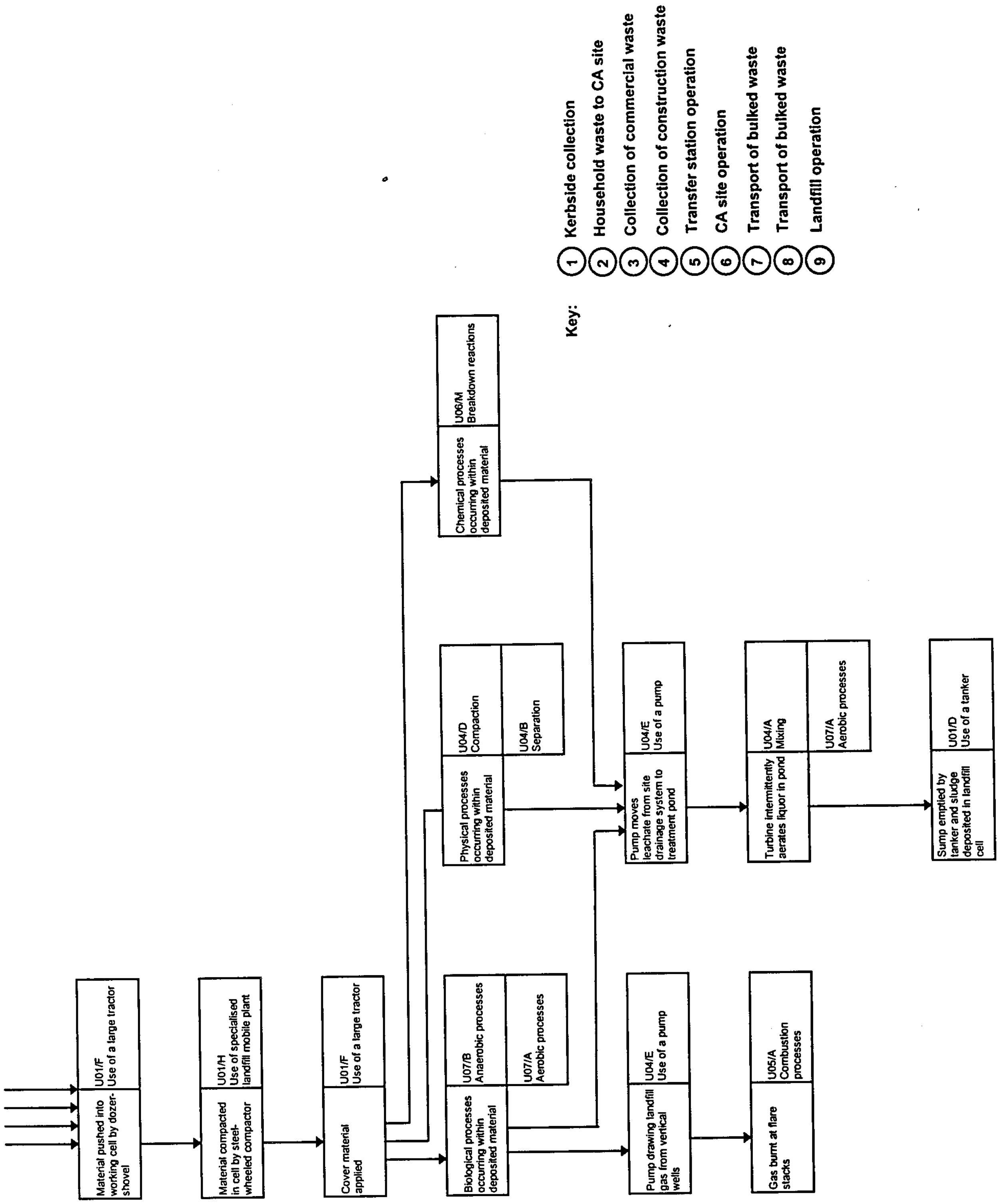
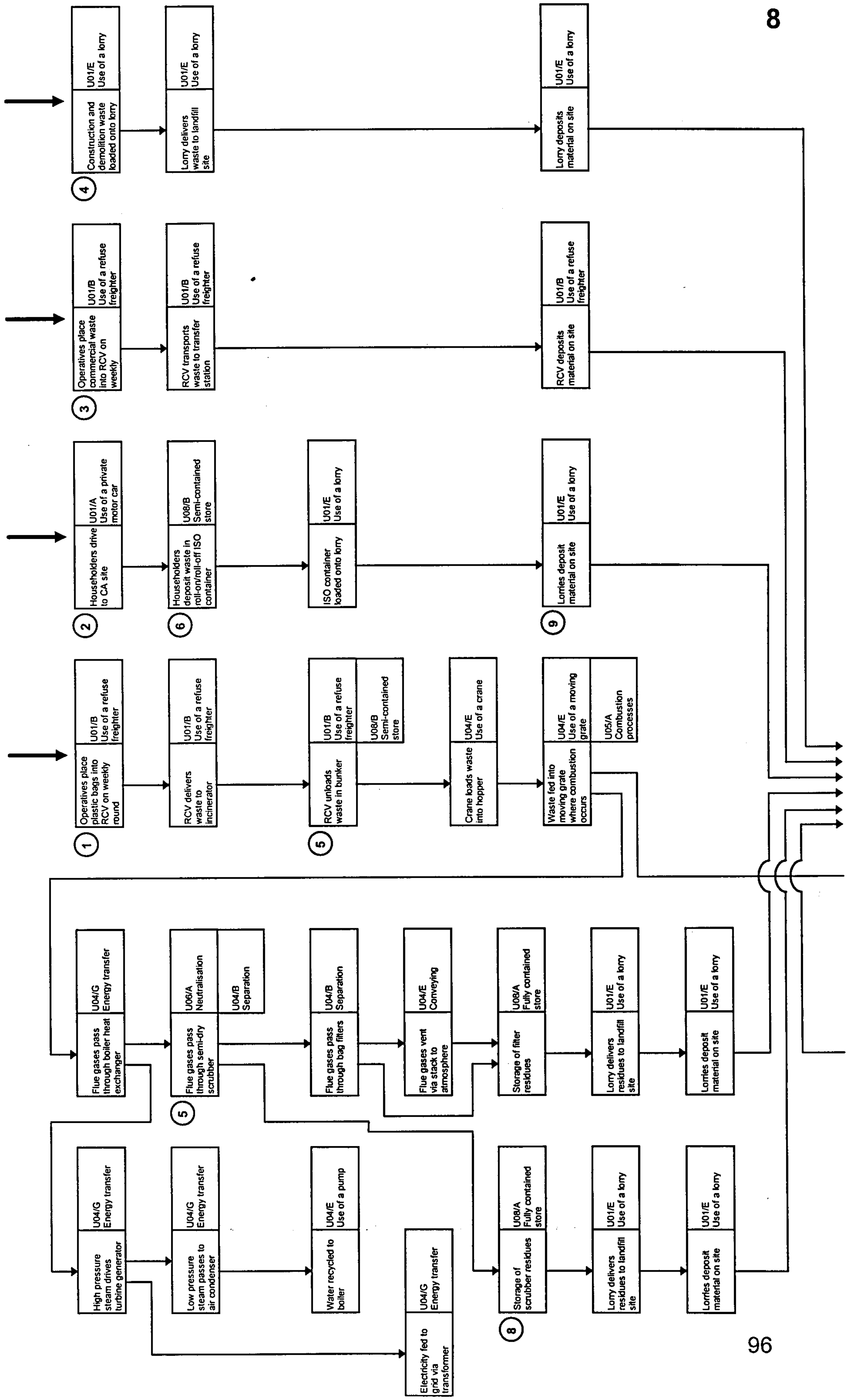

Material pushed into working cell by dozer-shovel
U01/F Use of a large tractor
Material compacted in cell by steel-wheeled compactor
U01/H Use of specialised landfill mobile plant
Cover material applied
U01/F Use of a large tractor
Biological processes occurring within deposited material
U07/B Anaerobic processes
U07/A Aerobic processes
Physical processes occurring within deposited material
U04/D Compaction
U04/B Separation
Chemical processes occurring within deposited material
U06/M Breakdown reactions
Pump drawing landfill gas from vertical wells
U04/E Use of a pump
Gas burnt at flare stacks
U05/A Combustion processes
Pump moves leachate from site drainage system to treatment pond
U04/E Use of a pump
Turbine intermittently aerates liquor in pond
U04/A Mixing
U07/A Aerobic processes
Sump emptied by tanker and sludge deposited in landfill cell
U01/D Use of a tanker
Key:
1 Kerbside collection
2 Household waste to CA site
3 Collection of commercial waste
4 Collection of construction waste
5 Transfer station operation
6 CA site operation
7 Transport of bulked waste
8 Transport of bulked waste
9 Landfill operation

Figure 8.6: Proposed Scenario - Process Descriptions and Unit Operations



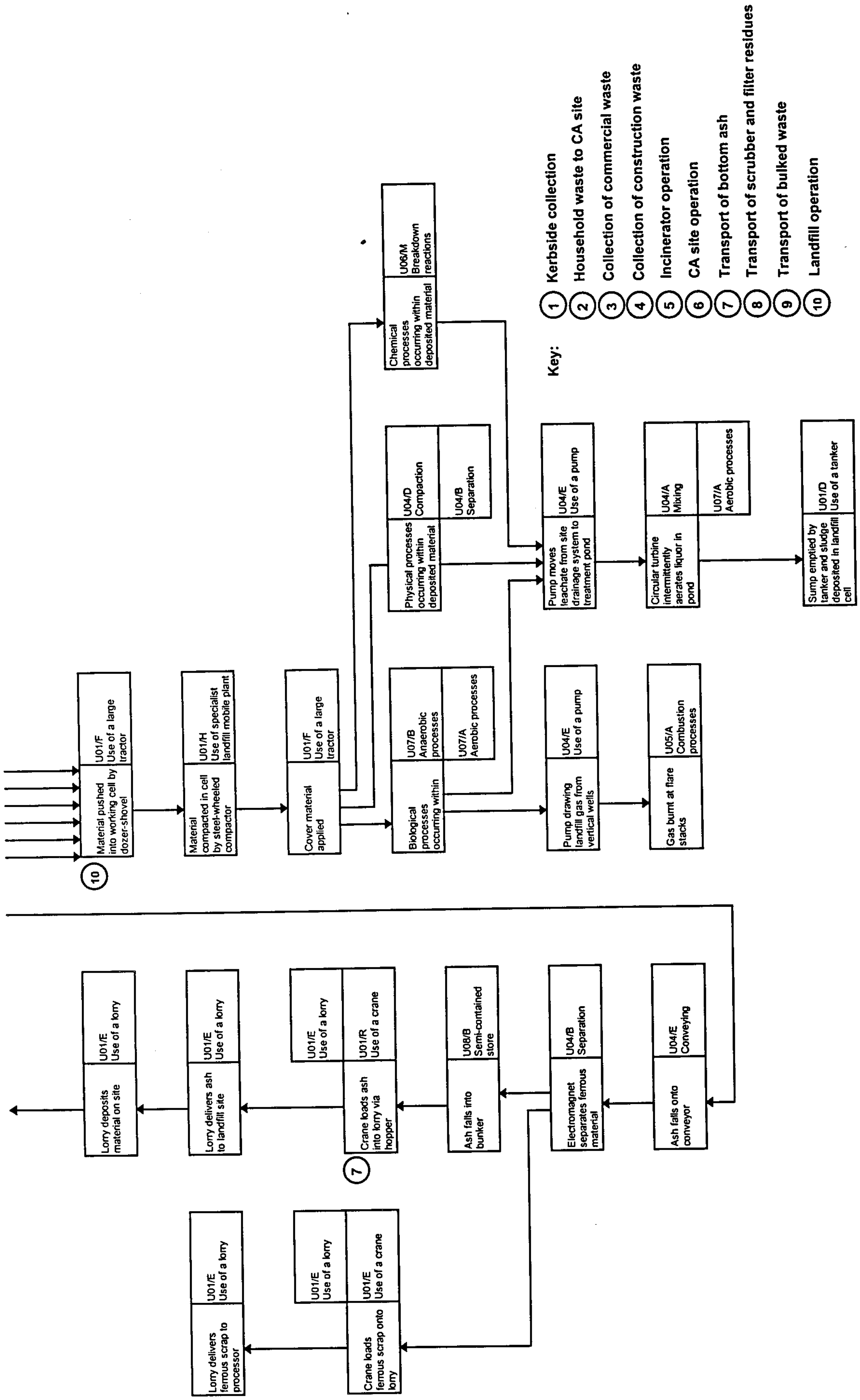

Key:
1 Kerbside collection
2 Household waste to CA site
3 Collection of commercial waste
4 Collection of construction waste
5 Incinerator operation
6 CA site operation
7 Transport of bottom ash
8 Transport of scrubber and filter residues
9 Transport of bulked waste
10 Landfill operation
Material pushed into working cell by dozer-shovel
U01/F Use of a large tractor
Material compacted in cell by steel-wheeled compactor
U01/H Use of specialist landfill mobile plant
Cover material applied
U01/F Use of a large tractor
Chemical processes occurring within deposited material
U06/M Breakdown reactions
Physical processes occurring within deposited material
U04/D Compaction
U04/B Separation
Biological processes occurring within
U07/B Anaerobic processes
U07/A Aerobic processes
Pump moves leachate from site drainage system to treatment pond
U04/E Use of a pump
Circular turbine intermittently aerates liquor in pond
U04/A Mixing
U07/A Aerobic processes
Sump emptied by tanker and sludge deposited in landfill cell
U01/D Use of a tanker
Pump drawing landfill gas from vertical wells
U04/E Use of a pump
Gas burnt at flare stacks
U05/A Combustion processes
Ash falls onto conveyor
U04/E Conveying
Electromagnet separates ferrous material
U04/B Separation
Ash falls into bunker
U08/B Semi-contained store
Crane loads ash into lorry via hopper
U01/E Use of a lorry
U01/R Use of a crane
Lorry delivers ash to landfill site
U01/E Use of a lorry
Lorry deposits material on site
U01/E Use of a lorry
Crane loads ferrous scrap onto lorry
U01/E Use of a lorry
U01/E Use of a crane
Lorry delivers ferrous scrap to processor
U01/E Use of a lorry

Table 8.3: Description of Proposed Scenario

This covers exactly the same area as the Existing Scenario.

Kerbside collection of household wastes. Black plastic bags are provided by the collection company. Weekly collection by RCV from the kerbside. Approx. 25% of carriage is commercial and industrial wastes.

Separate collection of commercial/industrial wastes. Collection made by a combination of FELs, RELs and skip loaders at approx. weekly intervals.

Civic Amenity site. Householders transport bulky items of waste to the CA site using private motor vehicles. At the site waste items are deposited in a walk-in ISO roll-on/roll-off container. The bulked waste is then transported to the landfill by lorry.

Incinerator. Waste is delivered to an enclosed tipping hall and deposited direct by the RCVs into a below ground level concrete bunker. The bunker has a forced draught dust suppression system. The refuse is transferred from the bunker to a feed hopper by two electrically powered crane/grabs.

The incinerator has two furnaces which are fed from the common refuse bunker. For each furnace waste is fed from the hopper onto a reverse-acting stoker grate by hydraulic ram feeders. After combustion residual bottom ash is discharged onto a conveyor belt residue handling system fitted with an electromagnetic ferrous metal separator. Bottom ash and ferrous scrap are stored in separate concrete bunkers and loaded onto lorries by crane/grabs for disposal to landfill.

Flue gases pass from the furnace through a boiler heat exchanger and then through a semi-dry gas scrubber. In the gas scrubber, a lime slurry is injected to cool and neutralise the gas, which then passes through a multi-compartment bag fitter before venting via a single common stack.

Superheated steam from the boilers is used to power a conventional turbine-driven generator, which feeds electrical power to the grid via a transformer. The spent steam is recovered using air-cooled condensers.

Collection of construction and demolition wastes. Wastes are transported direct from the construction sites to the landfill sites using a variety of high-sided trucks.

Landfill site. The landfill uses dozer-shovels to move waste into cells and spread cover material. Waste is compacted by steel-wheel compactors before covering.

The landfill is lined and has a leachate collection and treatment system. The treated leachate is discharged to sewer and therefore requires initial treatment only. This consists of an aerating batch reactor. An electric pump collects leachate from the site drainage system and delivers it to the treatment pond. Electrically-driven turbines aerate the liquor in the pond and are switched off at intervals, allowing the sludge to settle. Settled sludge is drawn off from the bottom of the pond by gravity to a sump. The sump is emptied by a suction tanker and the sludge deposited in a landfill cell. The treated effluent (supernatant) is drained by gravity to sewer.

There is a landfill gas collection and flaring system. Gas is drawn from a series of vertical wells by an electric fan and passed to a single flare stack where it is burnt. The flare stack is fitted with an electric/propane starter and a flame arrester. There are no facilities for energy recovery.

8.19 The next stage in the process would be to take each unit operation identified in Figures 8.4 and 8.5 in turn and identify the generic characteristics of the waste passing through each operation. This would then allow, with the help of the information given in Tables 6.2, 6.3 and 6.4, the waste independent and waste dependent burdens arising from each unit operation to be identified, according to the classification of burdens given in Table 6.1.

8.20 Burdens identified for a particular unit operation which are deemed to cross the system boundary at that point would then be quantified, expressed in terms of the functional unit, and added to the Inventory Table. Burdens which do not cross the system boundary at that point would be traced as a waste input to a subsequent unit operation.

8.21 Detailed identification and quantification of the environmental burdens associated with each scenario has not been possible at this time in the absence of a suitable software system and database. A preliminary identification of the environmental burdens has been made, however, and is given below. This exercise suffices to show how the systematic approach to the description of waste management systems and burden identification advocated in this report exposes the key environmental differences between the Existing and Proposed Scenarios.

Key Environmental Differences

8.22 The main sources of direct, indirect and avoided environmental burdens for the Existing and Proposed Scenarios are summarised in Tables 8.4, 8.5 and 8.6 respectively, with reference to the numbered operations shown in Figures 8.3 and 8.4.

8.23 This analysis shows that, as anticipated in the definition of initial system boundaries, the burdens arising from the four activities which the comparative scenarios have in common are virtually identical (i.e. transport of household waste to the CA site, operation of the CA site, separate collection of commercial/industrial wastes and separate collection of construction/demolition wastes). The key differences between the scenarios are shown to lie in burdens arising from:

- construction activities to build the new incinerator and associated demolition of the transfer station;
- the operation of the incinerator;
- changes to the operation of the landfill site; and,
- changes to the volumes of waste requiring transport.

These key differences are summarised in the boxes at the end of the chapter.

Table 8.4 Sources of Environmental Burdens for the Existing and Proposed Scenarios - Direct Burdens

FIXED BURDENS EXISTING SCENARIO	PROPOSED SCENARIO
( )* - Numbered operations in Figures 8.3 and 8.4)	
(1) Kerbside collection household/commercial waste: **(2) Household waste to CA site:** **(3) Separate collection commercial waste:** **(4) Separate collection construction waste:** **(7) Bulked waste from Transfer Station to Landfill:** **(8) Bulked waste from CA site to Landfill;** • Land take • Visual intrusion of garages/depots	**(1) Kerbside collection household/commercial waste:** **(2) Household waste to CA site:** **(3) Separate collection commercial waste:** **(4) Separate collection construction waste:** **(7) Bulked waste from Transfer Station to Landfill:** **(8) Bulked waste from CA site to Landfill:** • Land take • Visual intrusion of garages/depots
(5) Transfer Station: • Land take • Visual intrusion	**(5) Incinerator:** • Land take • Visual intrusion
(6) CA Site: • Land take • Visual intrusion	**(6) CA Site:** • Land take • Visual intrusion
(9) Landfill Site: • Land take • Visual intrusion	**(10) Landfill Site:** • Land take • Visual intrusion

Table 8.4 Sources of Environmental Burdens for the Existing and Proposed Scenarios - Direct Burdens (continued)

WASTE INDEPENDENT BURDENS EXISTING SCENARIO	 PROPOSED SCENARIO
(1) **Kerbside collection household/commercial waste:** (2) **Household waste to CA site:** (3) **Separate collection commercial waste:** (4) **Separate collection construction waste:** • Traffic noise • Local air pollution from vehicles • Traffic congestion • Oil on roads from vehicles • Generation of waste oil, lubricants, hydraulic fluid, tyres and batteries	(1) **Kerbside collection household/commercial waste:** (2) **Household waste to CA site:** (3) **Separate collection commercial waste:** (4) **Separate collection construction waste:** • Traffic noise • Local air pollution from vehicles • Traffic congestion • Oil on roads from vehicles • Generation of waste oil, lubricants, hydraulic fluid, tyres and batteries
(5) **Transfer Station:** • Noise • Local air pollution from front-bucket loader and manoeuvering RCVs and bulkers • Generation of waste oil, lubricants, hydraulic fluid, tyres and batters from front-bucket loader	(5) **Incinerator:** • Noise • Local air pollution from vehicles manoeuvering • Generation of fly ash and other filter residues • Generation of waste oils, lubricants • Generation of residues from boiler cleaning • Process-related stack emissions (e.g., particulates, CO, hydrocarbons, poly-aromatic hydrocarbons, dioxins, furans)
(6) **CA Site:** • Noise • Local air pollution from vehicles manoeuvering	(6) **CA Site:** • Noise • Local air pollution from vehicles manoeuvering

Table 8.4 Sources of Environmental Burdens for the Existing and Proposed Scenarios - Direct Burdens (continued)

WASTE INDEPENDENT BURDENS

EXISTING SCENARIO	PROPOSED SCENARIO
(7) **Transport of bulked waste from Transfer Station to Landfill:** • Traffic noise • Local air pollution from vehicles • Traffic congestion • Oil on roads from vehicles • Generation of waste oil, lubricants, hydraulic fluid, tyres, and batteries from vehicles	(7) **Transport of bottom ash from Incinerator to Landfill:** • Traffic noise • Local air pollution from vehicles • Traffic congestion • Oil on roads from vehicles • Generation of waste oil, lubricants, hydraulic fluid, tyres, and batteries from vehicles
	(8) **Transport of fly ash and other residues from Incinerator to Landfill:** • Traffic noise • Local air pollution from vehicles • Traffic congestion • Oil on roads from vehicles • Generation of waste oil, lubricants, hydraulic fluid, tyres, and batteries from vehicles
(8) **Transport of bulked waste from CA Site to Landfill:** • Traffic noise • Local air pollution from vehicles • Traffic congestion • Oil on roads from vehicles • Generation of waste oil, lubricants, hydraulic fluid, tyres, and batteries from vehicles	(9) **Transport of bulked waste from CA Site to Landfill:** • Traffic noise • Local air pollution from vehicles • Traffic congestion • Oil on roads from vehicles • Generation of waste oil, lubricants, hydraulic fluid, tyres, and batteries from vehicles
(9) **Landfill Site:** • Noise • Local air pollution from mobile plant and other vehicles manoeuvering on site • Generation of waste oil, lubricants, hydraulic fluid, tyres, and batteries from vehicles	(10) **Landfill Site:** • Noise • Local air pollution from mobile plant and other vehicles manoeuvering on site • Generation of waste oil, lubricants, hydraulic fluid, tyres, and batteries from vehicles

Table 8.4 Sources of Environmental Burdens for the Existing and Proposed Scenarios - Direct Burdens (continued)

WASTE DEPENDENT BURDENS EXISTING SCENARIO	PROPOSED SCENARIO
(1) **Kerbside collection household/commercial waste:** (2) **Household waste the CA site:** (3) **Separate collection commercial waste:** (4) **Separate collection construction waste:** • Odour • Litter • Dust	(1) **Kerbside collection household/commercial waste:** (2) **Household waste the CA site:** (3) **Separate collection commercial waste:** (4) **Separate collection construction waste:** • Odour • Litter • Dust
(5) **Transfer Station:** • Odour • Dust • Litter • Vermin	(5) **Incinerator:** • Odour • Dust • Litter • Vermin • Production of bottom ash • Production of flue gas scrubber residues • Waste-related stack emissions (e.g., CO_2, SO_2, HCl, HF)
(6) **CA Site:** • Odour • Dust • Litter • Vermin	(6) **CA Site:** • Odour • Dust • Litter • Vermin
(7) **Transport of bulked waste from Transfer Station to Landfill:** • Odour • Dust • Litter	(7) **Transport of bottom ash from Incinerator to Landfill:** • Dust (8) **Transport of fly ash, other filter and scrubber residues from Incinerator to Landfill:** • Dust

Table 8.4 Sources of Environmental Burdens for the Existing and Proposed Scenarios - Direct Burdens (continued)

WASTE DEPENDENT BURDENS EXISTING SCENARIO	 PROPOSED SCENARIO
(8) **Transport of bulked waste from CA Site to Landfill:** • Odour • Dust • Litter	(9) **Transport of bulked waste from CA Site to Landfill:** • Odour • Dust • Litter
(9) **Landfill Site:** • Odour • Litter • Dust • Vermin • Discharge of treated leachate to sewer • Surface run-off • Flaring of landfill gas	(10) **Landfill Site:** • Odour • Litter • Dust • Vermin • Discharge of treated leachate to sewer • Surface run-off • Flaring of landfill gas

Table 8.5 Sources of Environmental Burdens for the Existing and Proposed Scenarios - Avoided Burdens

EXISTING SCENARIO	PROPOSED SCENARIO
NONE	(5) **Incinerator:** • Export of grid electricity • Export of recovered ferrous scrap

Table 8.6 Sources of Environmental Burdens for the Existing and Proposed Scenarios - Indirect Burdens

WASTE INDEPENDENT BURDENS	
EXISTING SCENARIO	**PROPOSED SCENARIO**
(1) Kerbside collection household/commercial waste: **(2) Household waste to CA site:** **(3) Separate collection commercial waste:** **(4) Separate collection construction waste:** • Production of vehicles; RCVs, private motor vehicles and skip lorries • Production of consumables; petroleum spirit for private motor vehicles, diesel fuel for RCVs and lorries, lubricants, tyres and batteries for all vehicles and black plastic bags distributed to households	**(1) Kerbside collection household/commercial waste:** **(2) Household waste to CA site:** **(3) Separate collection commercial waste:** **(4) Separate collection construction waste:** • Production of vehicles; RCVs, private motor vehicles and skip lorries • Production of consumables; petroleum spirit for private motor vehicles, diesel fuel for RCVs and lorries, lubricants, tyres and batteries for all vehicles and black plastic bags distributed to households
(5) Transfer Station: • Production of front-bucket loaders • Production of consumables; diesel fuel for front-bucket loader and lubricants, tyres and batteries for vehicles • Production of grid electricity • Production of mains water	**(5) Incinerator:** • Demolition of existing Transfer Station; noise, dust, traffic congestion and generation of construction waste • Construction of new Incinerator; noise, dust, traffic congestion and production of diesel fuel for consumption by construction plant • Production of materials and equipment for construction of new Incinerator, including; structural steelwork, sand, cement, electrical wiring, general paperwork, hoppers and ducting, paint, boilers,reverse-acting grates and ram-feeders, ash handling conveyors and electro-magnet, crane/grabs for ash and ferrous metal disposal, flue gas scrubber, fly ash storage silo, bag-house filters, fans, steam turbine and AC generator, air-cooled condensers, transformer and power lines • Production of consumables; grid electricity during demolition, construction and operation, mains water during demolition, construction and operation, calcium hydroxide for gas scrubbers, water treatment chemicals for boiler water and lubricants

Table 8.6 Sources of Environmental Burdens for the Existing and Proposed Scenarios - Indirect Burdens (continued)

WASTE INDEPENDENT BURDENS EXISTING SCENARIO	PROPOSED SCENARIO
(6) **CA Site:** • Production of ISO containers • Production of grid electricity	(6) **CA Site:** • Production of ISO containers • Production of grid electricity
(7) **Transport of bulked waste from Transfer Station to Landfill:** (8) **Transport of bulked waste from CA Site to Landfill:** • Production of bulk freighters and skip lorries • Production of diesel fuel for bulk freighters and skip lorries	(7) **Transport of bottom ash from Incinerator to Landfill:** (8) **Transport of fly ash, other filter and scrubber residues from Incinerator to Landfill:** (9) **Transport of bulked waste from CA Site to Landfill:** • Production of freighters and skip lorries • Production of diesel fuel for freighters and lorries
(9) **Landfill:** • Production of capital items; landfill liner, leachate treatment plant, gas flaring system and mobile plant • Production of consumables; grid electricity, diesel fuel and mains water	(10) **Landfill:** • Production of capital items; landfill liner, leachate treatment plant, gas flaring system and mobile plant • Production of consumables; grid electricity, diesel fuel and mains water

Existing vs. Proposed Scenario – Key differences

DIRECT BURDENS

Fixed (non-flux)

- *Proposed Scenario:* visual intrusion of the new incinerator (especially stacks) may be greater than that of the existing transfer station, even though they will occupy the same site.
- *Proposed Scenario:* traffic congestion from the demolition of the existing transfer station and construction of the new incinerator will be an important local factor.
- *Existing Scenario:* land take for the landfill may be greater under the Existing Scenario in the long-term if current capacity is exceeded.

Fixed (flux)

- *Proposed Scenario*: noise and dust nuisance from construction of the new incinerator will be important local considerations.
- *Proposed Scenario:* significant quantities of demolition and construction wastes will be generated.

Waste independent/process related (flux)

- *Existing Scenario*: burdens from transporting bulked waste from the transfer station to landfill (noise, vehicle emissions, oil on roads, generation of waste oil) will be greater than transporting incinerator ash and residues to landfill, because volume of material from incinerator will be only 20% that of bulked waste from transfer station. (despite the distance involved being identical).
- *Existing Scenario*: vehicle burdens (e.g. noise, local air emissions, waste oil) likely to be greater under Existing Scenario at landfill site, because of greater throughput of waste.
- *Proposed Scenario*: incinerator operation will involve additional burdens compared with the transfer station, notably stack emissions of CO, NO_X ,dioxins and particulates.

Waste dependent product related (flux)

- *Proposed Scenario*: additional burdens from the incinerator operation will include stack emissions of CO_2, SO_2, HCl and HF.
- *Existing Scenario*: the potential for LFG production at the landfill site will be much greater than for the Proposed Scenario and the leachate generated will be higher in BOD/COD.

Existing vs. Proposed Scenario – Key differences (continued)

INDIRECT BURDENS

- *Proposed Scenario*: the construction of the new incinerator will require significant quantities of construction materials and capital plant and equipment.
- *Proposed Scenario*: the new incinerator will require more grid electricity, mains water and consumables than the current transfer station.
- *Existing Scenario*: transport of bulked wastes from the transfer station to the landfill site will require greater quantities of fuel and lubricants than will the transport of ash and residues from the incinerator, because of the significantly greater volumes of waste involved.
- *Existing Scenario*: the requirement for grid electricity, water, fuel and other consumables at the landfill site is likely to be greater because of the significantly greater throughput of material.
- *Proposed Scenario*: the incinerator operation will require significant volumes of alkali for the acid gas scrubbers.

Avoided burdens

- *Proposed Scenario*: the incinerator will export significant quantities of electricity and ferrous scrap.

Conclusions

9

Introduction

9.1 Decision making in the field of waste management is hampered by the absence of any consistent, objective, approach for assessing the environmental consequences of alternative management options. This is true both at a *national* level, in respect of waste management policy development, and at the *regional* or *sub-regional* level, where local authorities in particular need to make well informed choices in selecting the right technologies and facilities to meet their longer term resource recovery and residue disposal needs. A formal Environmental Impact Assessment (EIA), if required by the statutory planning process, will address some, but by no means all, of the environmental issues which may apply over the life-time of a specific facility. Moreover, an EIA is usually undertaken only after the decision to promote a particular option has been taken. An EIA thus focuses on mitigating the impacts of the chosen option, rather than acting as a tool to assess competing management solutions.

9.2 The lack of a standard process for assessing the environmental impacts of alternative waste management systems has significantly contributed to the contentious nature of most waste management proposals. What is urgently required is a tool for identifying and evaluating environmental impacts which is scientifically credible and enjoys the confidence of all parties affected by decisions, including the general public. Such a tool would complement other decision support methodologies, including the use of formal investment appraisal methods (DCF techniques, etc.) for the financial evaluation of alternative waste management strategies, as well as EIA.

9.3 The emerging discipline of Life Cycle Assessment is rapidly gaining support in other fields as an objective tool for discriminating between products and processes on the basis of their life-time environmental impacts. An international consensus on LCA methodology is developing. It is therefore entirely logical that the feasibility of applying LCA techniques to waste management decision making should be examined.

9.4 This study has consequently taken the LCA principles and guidelines, which have already been published and which continue to be actively developed by authorities in the field (notably SETAC and ISO), and sought to apply these to the management of non-hazardous wastes. As a first step, the current study has focused on Life Cycle Inventory Analysis (LCI), which is the first stage in conducting a full LCA and is concerned with defining the system to be studied and identifying and quantifying the associated environmental burdens.

The Potential of LCA to Assist Decision Making in Waste Management

9.5 The existing framework for conducting LCA studies has proved extremely useful in rationalising and clarifying the type and characteristics of the environmental burdens which potentially arise at different points in any waste management process. It is possible to distinguish between three main types of environmental burden:

- *Direct burdens*, which arise directly from the product or process under study;
- *Indirect burdens*, which arise from linked activities in the remainder of the economic system which are necessary because they provide materials and/or energy for the product or process; and,
- *Avoided burdens*, which account for any energy and materials generated which displace the energy and materials (and associated indirect burdens) produced by the activities in the remainder of the system.

9.6 In the context of waste management, direct burdens arise from all of the transport and operating processes which together make up the waste management activities proper within the system boundary. The waste management activities also largely determine the type and magnitude of the indirect and avoided burdens which need to be credited to the system and entered in the Inventory Table. The essential starting point in identifying and quantifying the environmental burdens associated with the system under study is therefore a detailed analysis of the waste management activities themselves.

9.7 Further consideration of the potential sources of burdens arising from the waste management activities shows that burdens arise because of the existence of the operating processes *per se* and/or because of a combination of these processes and the waste being processed itself. The systematic identification of environmental burdens therefore requires that the process operations and waste streams are first disaggregated and described according to a systematic and consistent formula.

9.10 A method for systematically and consistently describing both the waste management operations and the characteristics of waste streams using lists of common descriptors has therefore been developed as a key part of this study. The examples given in Chapters 5 and 8 show how this 'twin-track' methodology can be used to describe any combination of waste management activities in a consistent way and how this facilitates the identification and quantification of burdens.

9.11 The application of the existing LCI methodology to waste management has therefore prompted the development of a systematic framework for the identification of environmental burdens associated with waste management activities. This is a significant advance and provides a solid platform for comparing the environmental impacts of competing waste management systems.

Key Issues

9.12 This study has thus shown that LCA has great potential to satisfy the requirement for a systematic tool for comparing the environmental impacts of competing waste management systems. There is, however, a substantial amount of further development required before LCA can be routinely applied to waste management planning. In this respect there are two key issues, software development and the creation of a waste management database, which this study has highlighted:

Software development

9.13 General LCA methodology is still at a relatively early stage of development. The technique has been applied most successfully in other fields to relatively simple situations, especially studies on single product life-cycles. Moreover, most conventional LCA studies are further simplified by restricting, at the scoping stage, the range of burdens to be quantified. For example, burdens which comprise less than a certain proportion, typically 5%, of the total are often excluded and non-flux burdens ignored completely.

9.14 However, a distinguishing feature of waste management systems is their complexity and variability and the wide range of sources of potential burdens which exist within any system. It is not possible, nor desirable, to pre-judge which of these burdens may be significant. Furthermore, Lave *et al* (1995) have drawn attention to the dangers for Life Cycle Assessments of omitting sources of burdens using the *de minimis* principle, and have suggested that this can lead to indirect burdens in particular being significantly under-estimated. For all these reasons it would therefore be unsafe to restrict the range of burdens to be included in waste management Inventory Tables, and non-flux burdens in particular must be addressed.

9.15 A major challenge in developing LCA as a technique for waste management will be dealing with the complexity involved in comprehensively describing real-life waste management systems and identifying all potential sources of burdens. The solution to this problem must lie in the use of appropriate software to assist the analysis. Existing software systems which have been developed to facilitate LCAs in other fields are not, as they stand, adequate for this task. The development of new software, or substantial modifications to existing software, will therefore be required to take the application of LCA forward in the field of waste management.

Waste management database

9.16 Having identified all the sources of environmental burdens, the next challenge will be to collect relevant data. Previous experience in LCA suggests that data collection often accounts for the greatest single expenditure of time and resources in conducting a study. Furthermore, good data often simply do not exist, although the quality and accuracy of the data are fundamental to the usefulness of the results of any LCA.

9.17 The routine application of LCI to waste management will therefore require a national database which users can access to obtain data on common burdens. Many indirect burdens, for example those associated with electricity and fuel production, will be common across almost all studies. In addition, direct burdens from individual unit operations, for example vehicle usage and waste handling and conveying systems, will also be common to many waste management systems.

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Glossary

In this report, the following terms and definitions apply:

Aerobic process: A microbiological process which requires the presence of oxygen.

Allocation: Technique whereby environmental burdens are partitioned between multiple inputs or outputs of a defined system.

Anaerobic process: A microbiological process which requires the complete absence of oxygen. Anaerobic bacteria are often poisoned by the presence of oxygen.

Avoided burdens: Environmental burdens associated with the background system which are avoided because of recycling of materials or energy recovery taking place in the waste management activities.

Biogas: A mixture of gases generated by microbiological processes, typically in landfills and anaerobic digestors, which comprises methane and carbon dioxide in varying, but often equal proportions, and with methane seldom more than 60% by volume. Also contains small amounts of other gases.

Bottom ash (clinker): The residue that collects in the bottom of the burning chamber of an incinerator. Bottom ash includes all the solid materials that pass through the furnace un-burnt, such as glass, metals, rocks, soil, car parts and broken appliances.

Bring facilities: These are recycling facilities which require clean segregated material to be delivered and deposited by members of the public at dedicated collection sites such as glass and paper banks.

Calorific value: The quantity of heat produced by the complete combustion of a given mass of a fuel, usually expressed in Joules per kilogram.

Characterisation: Substep of the LCA Impact Assessment in which the classified inventory parameters are processed into a common unit characterising the impact category and, where possible, aggregated.

Civic amenity site (CA site): A dedicated site provided by the Local Authority for local residents to dispose of bulky household items such as garden wastes, old appliances, carpets, etc.

Classification: Substep of the LCA Impact Assessment in which all input and output flows of the system are assigned to one or more impact categories representing an environmental effect.

Closed-loop recycling: A recycling process in which an output from a system, which would otherwise be a waste, is returned to the system, with or without treatment, to contribute to production of the main product.

Data quality: The degree of confidence in individual input data from a source, aggregated data and in the dataset as a whole. LCA data quality is described by the data quality indices (DQIs) selected for the study.

Data: LCA data is the collective term for all data and information (quantitative and qualitative) used in performing LCAs. This may include raw data as well as intermediate data obtained through manipulation. LCA data come from disparate sources and are of various types.

Depletion: Reduction in the global stock of raw material as a result of extraction of non-renewable resources (for example, mineral extraction or crude oil production), or extraction of renewable resources faster than they can be renewed (for example, de-forestation).

Direct burdens: Environmental burdens arising from the foreground system/waste management activities.

Environmental burden: Energy and raw materials used and waste released to air, water and land.

Environmental impact: Any change to the environment which, permanently or temporarily, results in loss of natural resources or deterioration in the natural quality of air, water or soil. The consequences for human health, for the well-being of flora and fauna or for the future availability of natural resources attributable to the input and output streams of a system.

Fixed burdens:	These are 'process related burdens' that arise due to the physical existence of the operation alone, for example, visual intrusion, land use and burdens associated with construction and decommissioning.
Fly ash:	The fine particles of ash in flue gases that are captured and collected by pollution abatement technologies.
Functional unit:	The unit of measure of performance of the main functional output of the product or service system.
Goal definition:	Part of the goal definition and scoping element of the LCA process leading to an unambiguous statement of the reason for carrying out the LCA, the intended use(s) of the results the intended audience, the initial data quality goals and the type of initial review process to be employed (if any).
Impact assessment:	The element of the LCA process aimed at a technical, quantitative and qualitative classification, characterisation and valuation of the magnitude and significance of environmental impacts based on information to the inventory analysis.
Indirect burdens:	Environmental burdens associated with the background system.
Inherent energy (also intrinsic energy or energy of material resources):	The gross calorific value of material inputs.
Interpretation:	Interpretation is the part of LCA where the inventory and impact assessment results are assessed in line with the goal and scope of the study.
Inventory analysis:	The element of the LCA process where data are compiled to quantify all environmental burdens throughout the life cycle of a given product or service system.
Kerbside facilities or collect systems:	These facilities require the householder to put out clean recyclable materials for specific collection from outside the property.

Landfill: The engineered practice of depositing waste into or onto land with final restoration to provide land for alternative use.

Landfill gas: Produced as a result of the decay of the organic components of waste deposited in landfill sites, under anaerobic conditions, by a mixed population of micro-organisms. The gas is comprised principally of carbon dioxide and methane, in varying, but often approximately equal concentrations, depending on the age and nature of the waste and a number of environmental factors. The gas also includes trace concentrations of a range of other gases.

Leachate: The result of liquid seeping through a landfill or other waste management processes and by so doing extracting substances from the deposited wastes.

Life cycle assessment: A systematic set of procedures for compiling and examining the inputs and outputs of materials and energy and the associated environmental impacts directly attributable to the functioning of a product or service system throughout its life cycle.

Life cycle: The consecutive and inter-linked stages and all directly associated significant inputs and outputs of a system, from the extraction or exploitation of natural resources to the final disposal of all materials as irretrievable wastes or dissipated energy. Also termed 'the cradle to the grave'.

Local authority waste disposal company (LAWDC): Local Authority Waste Disposal Company established at 'arms length' from other Local Authority institutions to provide waste disposal services in a fully commercial environment and in competition with private sector waste management companies.

Mass burn: Incineration plants which combust MSW without any processing or separation other than the removal of exceptionally large items that are too large to be fed into the combustion unit.

Materials recovery facilities (MRFs): A facility to process single materials from recycling schemes using a combination of mechanical technologies and hand picking techniques.

Municipal solid waste (MSW): All wastes collected by local authorities or their contractors from householders, commercial premises, and from CA sites delivered by local residents.

Non fossil fuel obligation (NFFO): Electricity generated from non-fossil fuel sources can, if awarded a contract, attract premium prices under the Non-Fossil Fuel Obligation introduced under the Electricity Act 1989. A number of Renewable Energy Orders have been made for England and Wales and similar Orders placed for Scotland and for Norhtern Ireland.

Non-renewable resource: A natural resource that cannot be replaced or regenerated or brought back to its original state once it has been exploited (or used as an input to an economic system).

Open-loop recycling: A recycling process in which an output from a system, which would otherwise be a waste, is used as an input to another system, with or without treatment, to contribute to the production of a useful product.

Putrescibles: Waste which is liable to decay rapidly, including food, vegetable and fruit wastes and may sometimes include garden wastes. Does not include all organic material which may decay under anaerobic conditions (e.g. paper, wood etc.).

Recycling: A set of processes for diverting materials that would otherwise be disposed of as wastes, into an economic system where they contribute to the production of useful material.

Refuse derived fuel: This is produced by mechanical processing of waste using screens, shredders and separators to yield a combustible product. There are two man types of RDF, coarse and densified. Coarse RDF (c-RDF) is more suited for direct on-site use since it cannot be stored for any considerable period. Densified RDF (d-RDF) is produced by further processing including drying and pelletising to produce a fuel.

Renewable resource: A natural resource that is capable of regeneration when part of its stock is exploited (or used as input to an economic system), for example plants and animals, hydro and wind power.

System boundary: The interface between the system being studied and the environment or other economic systems (all inputs and outputs compiled in the inventory table enter or leave the system across the system boundary).

System: A collection of materially and energetically connected operations which performs one or more defined functions.

Transfer station: A facility where refuse collection vehicles deliver waste to a central transfer station where it is loaded into vehicles or containers for onward bulk transport.

Trommel: A cylindrical drum with holes of specific size that rotates about its central axis. 'Undersize' material (material smaller in diameter than the holes) falls through the holes and is thus separated from the 'oversize' material.

Technosphere: The full sphere of human activity.

Unit operation/ process: The smallest portion of a system or activity for which data are collected.

Valuation: Substep of the impact assessment element of the LCA process in which the results of the characterisation are compared (note: the valuation may involve the interpretation, further aggregation, weighting and ranking of data).

Waste dependent burdens: These are 'product related burdens' due to the combination of unit operation, throughput and the nature of the waste.

Waste independent burdens: These are 'process related burdens' due to the quantities of waste flowing through the operation irrespective of the specific characteristics of the waste.