THE USE OF LIFE CYCLE ASSESSMENT TOOLS TO DEVELOP SUSTAINABLE MUNICIPAL SOLID WASTE MANAGEMENT SYSTEMS

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ABSTRACT

Historically the main objectives of waste management have been to dispose of society’s waste and to protect public health. Increasing public awareness of environmental issues has added sustainability to this list. Solid waste management needs to be environmentally sustainable to reduce overall environmental burdens, and economically acceptable for all sectors of the community served. Integrated Waste Management (IWM) takes an overall approach to this, involves the use of a range of different treatment options and deals with the entire waste stream. The tool of Life Cycle Assessment (LCA) can successfully be applied to assess the environmental burdens and economic costs associated with IWM systems. IWM supersedes the commonly referred to waste hierarchy, which only provides a simplistic framework to aid in the selection of different treatment options. The hierarchy cannot measure the effectiveness of potential solutions for specific locations, either economically or environmentally. LCA compiles detailed information on overall energy balance, final emissions to air and water and total economic costs of any particular waste management strategy. Several different waste management strategies can be compared, and from the resulting LCA data, informed decisions can be made based on economics and environmental burdens. This approach allows the determination of the best practical environmental option for total solid waste management in any specific geography. It must be emphasised that life cycle tools are decision support tools, not decision making tools.

SUSTAINABLE DEVELOPMENT AND WASTE MANAGEMENT

So what is sustainable development – and what does it mean for waste managers as we move into the 21st Century? It’s been the subject of a recent World Summit in Johannesburg, and a topic that has been taken up widely by governments. The UK has a sustainable development strategy, and has just published its latest assessment report. At the European level we also have an EU Sustainability Strategy.

An early problem was how to explain sustainability to the man in the street. Early definitions were complex, but the UK Government has developed a simple, yet aspirational description: “Sustainable Development is a simple idea. It is about ensuring a better quality of life for everyone, now and for generations to come”. For a country, sustainable development covers a whole range of “quality of life indicators”. The UK has 15 “headline indicators” which measure a range of aspects. There are 3 main areas in which indicators have been identified; economic measures like GDP, social aspects such as crime levels and educational achievement, and environmental areas such as river quality and biodiversity.
In line with these three areas of sustainable development, solid waste management needs to be economically affordable socially acceptable and environmentally effective (see Figure 1).

- Economic affordability requires that the costs of waste management systems are acceptable to all sectors of the community served, including householders, commerce, industry, institutions and government.
- Social acceptability requires that the waste management system meets the needs of the local community, and reflects the values and priorities of that society.
- Environmental effectiveness requires that the overall environmental burdens of managing waste are reduced, both in terms of consumption of resources (including energy) and the production of emissions to air, water and land.

![Sustainability diagram](image)

Figure 1. Sustainability balances environment, economy and society.

**THE WASTE MANAGEMENT HIERARCHY**

Past decisions on waste management strategy and the structure of waste management systems have relied either explicitly, or implicitly, on the "waste management hierarchy". This has varied in its exact form, but usually gives the following order of preference: waste reduction; re-use; materials recycling; composting; incineration with energy recovery; incineration without energy recovery; landfilling. Although the hierarchy has the advantage of being simple and providing a rule of thumb guide to the relative environmental benefits of different options, the use of such a priority list has its limitations.

The hierarchy has little scientific or technical basis. There is no scientific reason, for example, why materials recycling should always be preferred to energy recovery in every real life situation. The hierarchy is also of little use when combinations of options are used, as in an integrated waste management (IWM) system. In an IWM system, the hierarchy cannot predict, for example, whether composting combined with incineration of the residues would be preferable to materials recycling plus landfilling of residues. Finally and perhaps most importantly the hierarchy does not consider economic issues.

Recently Denmark's Environmental Assessment Institute (EAI) issued a report challenging the EU's waste hierarchy. Under the hierarchy, waste prevention is preferred to recycling, then recovery and finally disposal. The report concluded that the hierarchy should be considered only "a very general and flexible guideline" for formulating policies (EAI, 2005).
The hierarchy therefore should be used as a guide to options that need to be considered in an integrated waste management strategy and then decisions on which mix of options should be based on an overall assessment of the whole system, which only LCA, when applied with other decision-making criteria can provide.

INTEGRATED WASTE MANAGEMENT

A key question is how can we assess the overall environmental effectiveness and economic affordability of waste management systems, so that we can plan more sustainable waste management for the future? Along with the overall need for sustainable waste management, it is also becoming increasingly clear that no one single treatment method can handle all materials in municipal solid waste (MSW) in an environmentally efficient way. Following a suitable collection system, a range of treatment options will be required, including materials recovery, biological treatment (composting and/or biogasification), thermal treatment (burning of refuse-derived fuel (RDF), packaging-derived fuel (PDF) and/or mass-burn incineration) and landflling (Figure 2). Together these can form an Integrated Waste Management (IWM) system.

Effective schemes need the flexibility to design, adapt and operate systems in ways which best meet current social, economic and environmental conditions. These are likely to change over time and vary by geography. The need for consistency in quality and quantity of recycled materials, compost or energy, the need to support a range of disposal options and the benefit of economies of scale, all suggest that IWM systems should be organized on a large-scale, regional basis. Any scheme incorporating recycling, composting or energy from waste technologies must be market-orientated.

Whilst it uses a combination of options, the defining feature of an IWM system is that it takes an overall approach to manage all materials in the waste stream in an environmentally effective, economically affordable and socially acceptable way (White, 1995). IWM systems can be optimized using the tool of Life Cycle Assessment.

Figure 2. Elements of an Integrated Waste Management system
THE BASIC PRINCIPLES OF LIFE CYCLE ASSESSMENT

Life Cycle Assessment is an environmental management tool used to aid understanding and compare the impacts of a product or service ‘from cradle to grave’. The technique examines every stage of the life cycle, from raw materials acquisitions, through manufacture, distribution, use, possible reuse/recycling to final disposal. Every operation or unit process within a stage is included and for each operation within a stage, the inputs (raw materials, resources and energy) and outputs (emissions to air, water and solid waste) are calculated (the Life Cycle Inventory). These inventory inputs and outputs are then aggregated over the life cycle and environmental issues associated with these inputs and outputs can be evaluated further by Life Cycle Impact Assessment. Other decision-making tools can then be combined with this information to interpret the results. Conducting LCAs for alternative products or services thus allows for improved understanding and comparisons to be made. The results from an LCA will not necessarily guarantee that one can choose which option is better than another, but it will allow the trade-offs associated with each option to be assessed and interpreted by a decision-maker. With respect to waste management, the results of an LCA certainly cannot prescribe that one option must be selected over another, as all decisions supported by LCA results must be made with the full consideration of specific local conditions, including economic and social factors. An explanation of these LCA terms and their important differences is given in Table 1.

Table 1. Life Cycle terminology

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<th>Term</th>
<th>Description</th>
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<tr>
<td>Life Cycle Assessment</td>
<td>A process to analyse the materials, energy, emissions, and wastes of a product or service system, over the whole life cycle ‘from cradle to grave’, i.e. from raw material mining to final disposal. Currently considered to consist of four stages: Goal Definition, Inventory Analysis, Life Cycle Impact Assessment and Life Cycle Interpretation.</td>
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<tr>
<td>Goal Definition and Scope</td>
<td>Stage at which a functional unit for comparison is defined. The functional unit is the unit of analysis for the study and provides the basis for comparison if more than one product or system is being compared (normally per equivalent use). The Goal Definition and Scope stage also defines the study purpose, system boundaries, life cycle stages, unit processes and scope of the assessment.</td>
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<tr>
<td>Life Cycle Inventory Analysis</td>
<td>Process of accounting for all the inputs and outputs of the product system over the life cycle. Will result in a list of raw material and energy inputs, and of individual emissions to air, water and as solid waste which describes the overall environmental burden of the product or service.</td>
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<tr>
<td>Life Cycle Impact Assessment</td>
<td>Associates the inventory inputs and outputs with particular environmental issues, e.g. ozone depletion, and converts the inventory of materials, energy, and emissions into representative indicators, e.g. an aggregate loading of ozone-depleting chemicals.</td>
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<tr>
<td>Life Cycle Interpretation</td>
<td>Evaluation of the significance of the inputs, outputs, and indicators of the system life cycle. This stage is the least well accepted or defined.</td>
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In the context of sustainable development LCA will provide a quantitative assessment of the potential environmental impacts to inform the wider decision making process, that includes both the economic and social aspects of waste management systems. As techniques are
developed further, it is likely that Life Cycle Assessment will find many additional applications.

The benefits of a Life Cycle approach

Life Cycle Assessment is an inclusive tool. The Life Cycle Inventory phase is essentially an environmental accounting process or mass balance for a system. All necessary inputs and emissions in many stages and operations of the life cycle are considered within the system boundaries. These include not only direct inputs and emissions for production, distribution, use and disposal, but also indirect inputs and emissions, such as from the initial production of the energy used. To conduct a fair and transparent analysis it is essential that the boundaries of the study be clearly defined and all the necessary processes are included. The results are assessed holistically in that the Inventory is aggregated over time, so all inputs and emissions over the whole life cycle are included regardless of when they occur, and aggregated over space, i.e. all of the sites are included, regardless of where they are located. It is important to use LCA to achieve real environmental improvements so that changes to any system do not cause greater environmental deteriorations at another time, in another environmental medium, or at another location in the life cycle.

LCA offers the prospect of mapping the energy and material flows as well as the resources, solid wastes, and emissions of the total system. Comparing such system maps for different options, whether for different products or waste management systems, allows the identification of areas where environmental improvement can be made.

Concern over the environment is sometimes expressed in terms of single issues, such as acidification or incineration. Concentrating on one issue alone, however, ignores and may even worsen the system with respect to other environmental issues. The power of LCA is that it expands the debate on environmental concerns beyond a single issue, and attempts to address a broad range of environmental issues. By providing a quantitative methodology it also gives an objective basis for decision-making and can help to take some of the emotional element out of environmental debates.

The limitations of a Life Cycle approach

The seemingly all-encompassing nature of LCA has proved very attractive. It may appear to new users that it is a single tool that can accomplish ‘everything’ with regard to environmental assessment. Many people have viewed LCA as being able to give a comprehensive, overall assessment of a product, service or package. As a result, there have been ill-advised efforts to use LCA as the only measurement tool when developing product-labelling systems and during policy making.

There is a dilemma at the heart of LCA. Since LCA aggregates resource use, solid waste and emissions over time and space, LCA can identify generalised potential impacts (for example, the Global Warming Potential of Carbon Dioxide emissions release over the entire life cycle), but is not able to assess actual environmental impact. The International Standards Organisation (ISO) Life Cycle Impact Assessment document (ISO 14042, 2000) specifically cautions that LCA does not predict actual impacts or assess safety, risks, or whether thresholds are exceeded. The actual environmental effects of emissions and wastes will depend on when, where and how they are released into the environment, and other assessment tools and information must be utilised.
For example, an aggregated emission, if released in one event from a point source such as a refinery, will have a very different environmental effect than releasing it continuously over years from many diffuse sources. In addition to this, the inventory will allocate the inputs and outputs of a refinery to many products, i.e. different product systems. Recalling that LCA deals with only the inputs to a single system, only a small percentage of the total activity will be considered for a single product.

The dilemma, therefore, is that LCA is the only tool that attempts to include the whole life cycle, and all environmental issues associated with a product, package or service system, and the only one that relates this to the functional unit, yet it does not predict the actual localised environmental effect likely to occur. Other tools, such as risk assessment, are able to predict the likelihood of local environmental damage, but they do not cover all environmental issues in the life cycle, neither do they link the effects to the functional unit.

Clearly no single tool can do everything – a combination of tools and approaches with complementary strengths is needed for overall environmental management.

**Life Cycle tools for individual products and packages**

Most early LCA tools and studies have looked at the life cycles of individual products or packages. The functional unit for such studies is normally defined in terms of providing the function of the product (e.g. the washing of clothes), or in the case of packaging, it is usually defined as delivering a certain weight or volume of product to the consumer. The study boundary includes the whole life cycle of the specific product, from raw material extraction, through manufacture, distribution, and use to post-use waste management (with possible recovery/recycling).

**Life Cycle tools for solid waste management systems**

It is also possible to apply LCA to services such as solid waste management. In this case, the functional unit is “the management of an amount of solid waste from a given specified region”. The life cycle of solid waste runs from the moment that the material becomes waste (i.e. when it ceases to have value or is discarded), through the treatment processes in the solid waste system until the material ceases to be waste, by becoming an emission to air or water, inert material in a landfill, or by becoming a useful product again through a valorisation process.

Clearly there are overlaps between the two LCA approaches, since the LCA for a product includes the time the particular product spends in the waste management system, and the LCA for waste includes the waste management stages of all products and packages. There are fundamental differences, however, since the two applications have different functional units, and therefore different uses (and potential users). A product LCA can be used to optimise a specific product life cycle, normally within a given infrastructure system (energy generation system, transport system, solid waste management system etc.). A solid waste LCA, by contrast, aims to compare options and optimise the infrastructure system for managing a given amount and composition of waste. In a solid waste LCA all life cycle stages prior to the product becoming waste can be omitted if they are common to all the subsequent waste management options. But, if the waste LCA does consider recycling then credits for the avoided environmental burdens of virgin material production should be given. In this case the
waste LCA also needs to take into account the relevant stages of the subsequent recycled product. Hence product LCAs are of use to those that control product design and manufacture; solid waste LCAs are of use to those that plan or manage solid waste management systems. They represent two different applications of LCA for two different user groups.

**CHOOSING THE RIGHT TOOL FOR THE JOB**

Appreciating this distinction is important since different questions relating to product and waste management will require the choice of the appropriate tool. For example, a solid waste LCA attempts to assess the environmental burdens of the waste, once produced. Since it takes the solid waste as a given (the zero burden approach), this method cannot be used to assess how waste prevention can best be achieved, since this occurs prior to the creation of waste. It can look at the consequences of changes in waste composition and the size of the waste stream, which may arise through waste prevention measures, on the waste management system, but cannot identify how and where waste prevention should occur. Since each product system will be different, the opportunities for waste prevention must be identified on a product-by-product basis, through the use of product LCAs. Therefore, comparisons of product systems, such as opportunities for re-usable packaging versus one-way packaging systems, need to be done using a product LCA, on a product-by-product basis.

In contrast, comparisons between treating a given waste by recycling, composting, energy from waste or landfiling, and how to achieve the optimal combination of such options in an integrated solid waste management system, can be achieved using a solid waste LCA. All life cycle stages prior to the product becoming waste can be omitted if they are common to all the subsequent waste management options.

**CURRENT LCA TOOLS FOR IWM SYSTEMS**

Life cycle tools are already being used to optimise integrated waste management systems in Europe, North America and Latin America (Mexico, Venezuela and Brazil) and most recently in Asia (China and Japan), where they have been successfully applied to a wide range of waste management issues in widely differing waste management systems. This has proved that they are appropriate techniques to help countries with both developed and developing economies to establish sustainable waste management systems. A number of life cycle tools for waste management are currently available.

The UK Environment Agency’s Life Cycle Research program began in 1994. The software tool WISARD (Waste Integrated Systems Assessment for Recovery and Disposal) has been fully peer reviewed and has been available from the UK Environment Agency since 1999. This model has been the basis of parallel models developed (by the inclusion of country specific data) by the Scottish Environmental Protection Agency and the French Environmental Protection Agency. A specific version of WISARD was also developed for New Zealand and further case studies were run in Spain, Italy and Japan. The current version (4.0) focuses on the most sensitive parameters identified within waste management. The scope of the tool encompasses municipal waste collection, landfiling, incineration, composting, anaerobic digestion and recycling of packaging and newsprint. The tool contains a database for technical parameters describing site operations on waste management sites.
The second version of this UK Environment Agency model now called WRATE (Waste and Resources Assessment Tool for the Environment) is currently under development. This model allows the user to change municipal solid waste composition and quantity as well as details of the collection regime, vehicle types and waste management method in order to produce a LCA for the entire municipal waste management system. As of March 2005, the model incorporates data for most waste management facilities available in the UK. The complete integration of the LCIA methods, results, functionality and interpretation will be made available at the release date of the full product in October 2005.

The US Environmental Protection Agency, through a cooperative agreement with the Research Triangle Institute and its partners, has developed a Municipal Solid Waste Decision Support Tool (MSW DST) and Life Cycle Inventory (LCI) Database for North America. This research began in 1994 and has involved a wide range of stakeholder support, peer review, and quality assurance. The MSW DST is available for use in local and regional studies and enables communities to evaluate the life cycle environmental tradeoffs and full costs of integrated solid waste management strategies. Applications of the MSW DST have been conducted in over 20 communities and regions providing input leading towards more environmental and economic strategies for solid waste management. The LCI Database was released in the autumn of 2003. A web-based version of the MSW DST is currently under development.

Two Canadian industry groups, Corporations Supporting Recycling (CSR) and the Environment and Plastics Industry Council (EPIC) have co-sponsored the development of a LCI model for waste management systems. The model has been designed with input from the City of London, Ontario. The City of London’s participation has provided an excellent case study in which data inputs, analyses, interpretation and results have been conducted by and communicated to stakeholders. The peer review process ended in April 1999. The release of the model began soon after, and training workshops are currently being carried out across Canada. The University of Waterloo in Ontario, Canada now provides technical support for this model.

ORWARE is a tool for computer aided environmental systems analysis of municipal waste management. It includes sub models of e.g. waste collection and treatment facilities, which are linked to design different waste management systems. The model calculates emissions, energy turnover, potential environmental impact, and costs from a life cycle perspective. A so-called enlarged system is also included with conventional production of products that may be recovered from waste, e.g. electricity, heat, fertiliser, and materials, to capture the net impact of resource recovery from waste. This model has been developed by the Department of Chemical Engineering / Industrial Ecology, Royal Institute of Technology in Stockholm, Sweden.

The Fms-model developed by the Centre for Environmental Strategies Research, Sweden, covers national Swedish waste management. It is implemented in the generic LCA software SimaPro. It was recently applied in evaluation of a Swedish waste tax proposal.

IWM-2 (McDougall et al. 2001). This updated version of IWM-1 (a LCI tool for waste management systems released in 1995) is a stand-alone Windows program that contains updated global data. User friendliness and modelling flexibility have been improved. The transparency of both data and calculations has been maintained. The model has also been peer
reviewed by a group of international experts and the recommendations of the reviewers have been included in the final development of the model. The IWM-2 model is an entry level LCI tool and is ideal for familiarizing users with the approach taken, the data requirements of Life Cycle work and the interpretation of results from such models. This model is part of a book on IWM and LCA that has now been translated from English into Spanish, Chinese and Japanese.

**CONCLUSIONS**

The earliest Life Cycle models for solid waste management were no more than a first attempt to apply the technique to this new field. Talking to the users of such tools, it is clear that many improvements can and are being made. In particular, Life Cycle tools for Integrated Waste Management need to be:

1) Easy to use. They should be accessible to waste planners and managers, not just the domain of LCA experts or computer experts. Only if they are easy to use will full use be made of their potential to run creative “what if ..?” scenarios. Input from user groups will be essential to ensure the tools meet the needs of waste planners, managers and others.

2) Easy to understand and communicate to others. Endless tables of data do not communicate well. The Canadian model, for example, has provided an interesting way to dimension differences between options, by equating them to electricity consumption by homes, emissions from cars etc. (Thurgood, M., 1998).

3) Flexible. Users need to be able to customise the models so that they fit their specific circumstances.

4) Credible. If LCI results are going to be used as the basis for discussion between the many and varied stakeholders in waste management decisions, the tool needs to be credible. The methodology and assumptions must be transparent, and the basic data relevant and reliable. Having endorsement from the UK Environment Agency or the US Environmental Protection Agency may help to establish the credibility of models.

Environmental benefits cannot be engineered into the development of a waste management system unless that system is both economically viable and socially acceptable, hence all three areas must be addressed simultaneously. The environmental burdens associated with waste management systems can be calculated using the tool of LCA. The benefit of using a tool like LCA is that it provides flexibility by allowing assessment of the optimal waste management strategy for a given region, on a case-by-case basis rather than to try to identify a single solution for a whole country or continent. The role of waste management policy should be to set the desired objectives of waste management strategies, such as reduction of gases with Global Warming Potential or energy conservation. LCA can then provide an overall accounting tool to help reach these objectives. Hierarchies, in contrast, try to specify the means, rather than the desired end results. This can result in an overall increase in environmental pollution rather than a decrease, which can be achieved by a waste management system, optimized using the tool of LCA.

By adopting the use of LCA as part of the waste management decision making process countries can avoid the possibility of making serious long-term environmental mistakes by
rigid adherence to the hierarchy. Instead a Life Cycle databased decision making process will ensure that future investment in waste management will be reflected in overall environmental improvements.

REFERENCES


See http://www.blackwell-science.com/~cgilib/bookpage.bin?File=10013342
