ENVIRONMENTAL DESIGN TECHNIQUES FOR THE ELECTRONICS INDUSTRY.

Presented in Part Fulfilment for the Degree of Master in Science in Environmental Protection

by

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DEDICATION

To my husband, Brian,
and my daughters, Nicola and Karen.

For patience above and beyond the call of duty.

DECLARATION

This thesis has not been previously submitted to this or any other college and with, acknowledged accreditation, is entirely my own work.

ACKNOWLEDGEMENTS

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I wish to thank Dr. Tony Partridge, Sligo RTC for his invaluable advice and immeasurable patience in the completion of this work.
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ABSTRACT

Electronic products have increased dramatically in use in the last twenty years.

The level of environmental awareness has been raised by governments and consumers but confusion frequently surrounds the design of cleaner products and processes. Products have been labelled clean, earth friendly or green even though their impact on the environment maybe undocumented or unproved. Techniques are required to provide an effective means of measuring the environmental performance of a product. Issues relating to the environmental attributes of electronic products have instigated a review of product design techniques.

Design for the Environment (DFE) is a method by which the environmental considerations of a product can be integrated into process and product design practices. This is a new technique which is gaining interest in the electronics industry. Techniques proposed to assist designers and methods for improving the environmental performance of a product are observed.

Life Cycle Assessment is a technique used to evaluate the environmental concerns of a product throughout its life cycle.

The issues of waste and waste recycling are examined form the point of view of the proposed take back regulations in Europe and the status of electronic goods recycling is reviewed.

A case study using one of the design techniques to demonstrate the effectiveness is included.

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Chapter 1 Introduction

1.0 Introduction.

This thesis examines the techniques for adding environmental aspects into the design of electronic products. This industry is coming under pressure to put programmes in place to reduce the impact on resource use, eliminate hazardous materials and reduce the quantities of products entering the waste stream.

1.1 Design for the Environment

Design for the Environment (DFE) is a proactive approach to avoid environmental problems before they occur, rather than a reactive approach that tries to remedy them after they occur. Incorporating environmental considerations during the products design stage enhances that product's environmental performance throughout its life cycle. DFE is not one single method but a holistic approach to improvements in the design of products. It involves the integration of many functions within an organisation including facilities, finance, marketing, environment as well as the design department. Techniques include the design for remanufacture, disassembly, reuse and recycle.

1.2 Life Cycle Assessment

Life Cycle Assessment examines the environmental impacts of a product or process from the raw material extraction, to manufacturing, use and disposal.

By quantifying the environmental impacts of a product system from cradle to grave, Life Cycle Assessment (LCA) can generate ideas for reducing these impacts by means of process modifications, product redesign, material substitution or selection of an improved waste management option.

LCA contains four separate components, these are: Goal and Scope Definition; Life Cycle Inventory Analysis; Life Cycle Impact Analysis and Life Cycle Improvement Analysis.

The method has been endorsed by governmental, industrial, academic, and environmental professionals, in both North America and Europe. The International Standards Organisation have a draft standard for life cycle assessment as part of their environmental management series.

1.3 Electronic Goods Recycling

The high obsolescence rate of electronic goods means that this is becoming an increasing waste stream. The variety of materials in electronic goods compounds the difficulty in effective recycling. A review of the composition of electronic goods and the hazardous materials used was completed. As impending legislation may require manufacturers to take back their products and recycle them the status of electronic goods recycling and techniques to assist reuse are examined.

A case study using the environmentally design technique was completed to demonstrate one of these techniques in the application to a discrete electronic component.

Many questions remain in the industry concerning the optimum methods for recycling electronic products, or even whether such collection and recycling make good environmental and economic sense. These techniques aim to avoid the mistakes of the past of shifting environmental problems from one medium to another.

Objective

The purpose of this thesis is to examine the environmental aspects of electronic products. How the industry is implementing these issues in their products and what techniques are in use to aid designers. Specifically, this thesis will examine what Design for the Environment and Life Cycle Assessment are, and how they are adapted in the electronic industry. The status of the industry is explored in the electronics goods recycling. A case study using one of these techniques is used to demonstrate the effectiveness of the approach.

Chapter 2 Design for the Environment

2.1 Introduction

Design for the environment seeks to integrate product and process design in a single function to more effectively reduce aggregate environmental impacts associated with product systems. The objective is to examine the environmental aspects throughout the entire life cycle of the product .

New products are designed to meet a social or business need by a design or research and development department. In the past any environmental impacts of the production process were the responsibility of the environmental department of a company. Recent emphasis by governments on sustainable development and proposed European legislation on taking back waste electronic goods have changed this situation. The emphasis within companies has changed from that of pollution prevention measures within the manufacturing facility to environmental considerations in the use and the retirement stage of the product. The term used for this is design for the environment.

This chapter is a literature review of the background to design for the environment. This includes: a brief outline of the changes in European environmental legislation via the action programmes of the environment; the concept of industrial ecology, closed loop recycling and an explanation of an industrial ecosystem; the reasons electronic industries are now incorporating such procedures into their manufacturing processes; an explanation of the life cycle stages and the environmental criteria examined in a product; the development of methods by which environmental considerations can be included into the design of a new product and a detailed description of one of these methods. Also, examined, are the key methods of DFE : - remanufacture, reuse, disassembly and recycle. The DFE analysis tools available and the status of the integration in industry is examined via a survey. The chapter concludes with the issues perceived, recommendations and conclusions.

2.2 Background

In the past, product and process design have been treated as two separate functions in a linear design sequence: product design followed by process design. Concurrent engineering means examining the product and process design from the beginning. The design team must evaluate all the product development processes. These include improved functionality, performance, cost, quality, manufacturability and other issues important to the product's success in the marketplace (Veroutis, A. et al 1996a). Figure 2.1 is a schematic of all the attributes in a product development process and includes environmental considerations.

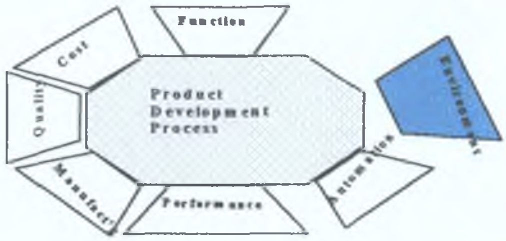


Figure 2.1 Product Development Process

As early as 1962, in *Introduction to Design,* Asimow developed a life cycle framework for engineering design (Asimow, M. 1962). A design project was organised into phases consisting of primary design, which included aspects of the function, quality, cost and performance of the product. The secondary phase was planning for the 'production-consumption cycle' which included production, distribution, consumption and recovery or disposal. In planning for retirement, he introduced the following guidelines which have been adopted by most current environmental design programmes:

- Designing physical life to match anticipated service life
- Designing for several levels of use so that when service life at a higher level of use is terminated the product will be adaptable to further use at a less demanding level.
- Design the product so that reusable materials and long-lived components can be recovered.

This concept was very advanced for the time. In 1962, there were few laws, mainly planning and licensing, for environmental control but there was little emphasis on environmental matters. Neither the life cycle framework nor the impacts of products on the environment were considered at that time. It is worthwhile reviewing the progression of legislation as it serves a indicator of the issues that have arisen over time.

2.3 European Action programmes for the Environment used in the development of environmental regulation.

There have been three distinct stages of environmental regulation since Earth Day 1970, when governments launched their first comprehensive attempt to improve the quality of the environment.

The European Union has used action programmes for the environment as a policy framework within which specific directives and regulations have been developed (Thorn, R. 1995).

2.3.1 European 1st and 2nd Action Programmes on The Environment

The first stage was 'end-of-pipe' regulations (European 1st and 2nd Action Programmes on The Environment). This, in essence was the creation of laws to prevent pollution:- e.g. Air Pollution Act; Water Pollution Act etc. The emphasis was on using regulations to enforce environmental issues. Many problems were encountered as industries tended to shift wastes from one medium to another. For example, air emissions were reduced by the use of wet scrubbers which then generated a water pollution problem. The water pollution generated waste sludge which generated solid waste problems.

Despite the deficiencies, end-of-pipe regulations appears to have significantly lowered industrial emissions. One of the strange anomalies of the system is that it only measures waste materials. A company could buy as much of a toxic material as it liked but the regulations only came into force when it tried to dispose of it. There was no emphasis on material usage, only on waste material that was for disposal.

2.3.2 European 3rd and 4th Action Programmes on the Environment

The second stage of environmental regulation began with the European 3rd Action Programme on the Environment in 1983. This introduced the principle of "prevention is better than cure" and focused on the industrial processes themselves. Reduction was the first priority, followed by recycling and then treatment and disposal. The 'Environmental Impact Assessment' Directive was passed, which signalled the beginning of the integrated approach to pollution control. The 4th action programme, which was adopted in 1987, can be included in this stage as it gave a legal basis to the 'polluter pays' principle and reinforced the integrated approach to pollution prevention.

2.3.3 European 5th Action Programme on The Environment

The third stage of environmental regulation was the European 5th Action Programme on The Environment, which came into force at the beginning of 1993 and will continue until the year 2000. A key element in this programme is the promotion of sustainable growth. This means that total strategies must be devised to protect the environment which will in turn allow the continuation of economic activity. This initiative seeks to achieve positive environmental outcomes while avoiding the stifling aspects of regulation. The general effects of these regulations have been to encourage 'clean technology' - production processes that use fewer toxic materials and that lead to fewer and less toxic effluents. The fifth action programme gives priority to areas where definite improvements must be achieved and include the following;

- The sustainable management of natural resources,
- Integrated pollution control and prevention of waste,
- Reduction of consumption of non-renewable energy,
- Coherent measures to improve environmental quality in urban areas,
- Improve public health and safety.

2.4 Industrial Ecology

The phrase 'Industrial Ecology' describes an industrial system that operates like a natural ecosystem. In nature, materials and energy circulate continuously in a complex web of interactions. Micro-organisms turn animal wastes into food for plants; the plants, in turn, are either eaten by animals or enter the cycle through death and decay. While ecosystems produce some actual wastes (by-products that are not recycled, such as fossil fuels), in the whole, they are self-contained and self-sustaining. A closed industrial ecosystem would be one which consumed limited resources and produced limited wastes through the continuous cycling of productive resources within the economy (Frosch, R. 1995).

In a similar fashion, industrial ecology involves focusing less on the impacts of each industrial activity in isolation and more on the overall impact of all such activities. This means recognising that the industrial system consists of much more that separate stages of extraction, manufacture and disposal and that the stages are linked across time, distance and economic sectors. Figure 2.2 is a diagram that demonstrates industrial ecology by looking at simple box models of industrial processes.

2.4.1 Closed Loop Recycling

Closed loop recycling means reusing the materials and products within the industrial system itself. Open loop recycling is where the products and waste are external to the industrial system.

Figure 2.2 A represents a familiar open loop system. Industry takes in new materials (M1) and processes them, generating both products (M2) and wastes (M3). The boundary of the system is such that both the products and the wastes are external to it. In a sense, they are general social responses or 'externalities'. Raw materials also come from outside the system. Where recycling takes place (M4), it represents a 're-entry' into the manufacturing system.

Figure 2.2 B represents an industrial ecology system. Raw materials still come from outside the system and certain wastes still leave it. Products and 'process wastes' remain within the system, where the producer accepts responsibility for the consequences of their use. Consumers are an integral part of the cycle. Instead of merely receiving goods and services, customers would use materials and energy temporarily, returning them to the industrial ecosystem for reprocessing and use.

There are three types of unusable wastes in the system: those generated during the extraction of new materials; those that leak from the recycling loop; and those lost through the use of the product. In contrast to Figure A products currently in use, or being held for recycling constitute a reservoir of materials available for use in the future (Frosch, R. 1995).

Figure A. An open system of material flow.

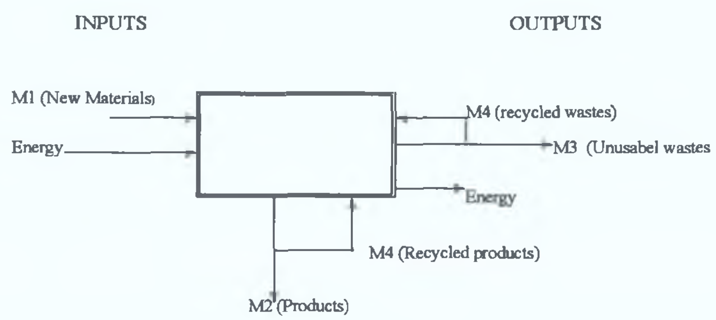


Figure B. A closed system of materials flow.

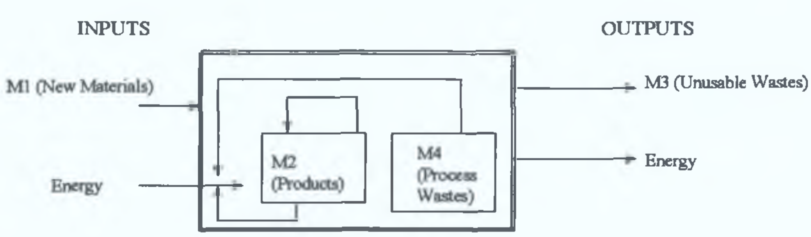


Figure 2.2 Box Model of Industrial Process

2.4.2 Industrial Ecosystems

The production and consumption of products are increasingly being seen not as unrelated events but as stages in the flow of materials. The idea is that a product can have a continuous life cycle, always being transformed for a new purpose. Thus, the whole industrial process can become a closed loop in which manufacturers retain responsibilities for their products until those products are reused (Allenby, B. 1996).

Industrial ecosystems support the cycling of materials and symbiotic relationships between businesses. As with natural systems linkages in business occurs at different spatial levels (that is, within and between companies at the local, regional, national and, in some instances, global level). In the latter case, the scarcity and value of materials such as platinum may warrant a global approach.

One example of interlocking is the development of a regional ecosystem for the cycling of materials used by automobile manufacturers in Europe such as Volkwagen and Mercedes- Benz.

An example of a local industrial ecosystem has been developed in Kalundborg. Denmark.

Over a twenty-year period, industrialists and municipal leaders in Kalundborg have found ways of using residual materials and energy productively for the economic and environmental benefit of all. The coal-fired power plant in Kalundborg for example, receives surplus gas and cooling water from a nearby refinery. It then delivers process steam to a pharmaceutical plant, and hot water to a fish farm and to the municipality for district heating. The gypsum removed from its scrubbers is delivered to a gyproc plant to offset a large percentage of the gypsum it had previously purchased in Portugal. The sulphur removed from the oil refinery's pollution control equipment is delivered to a sulphuric acid maker. The sludge from the pharmaceutical plant's operations goes to farmers for a fertiliser supplement (Frosch, R. 1995).

Since this system occurred more by good fortune than planning, a number of researchers are beginning to investigate strategic approaches and techniques for developing similar industrial ecosystems. In the United States, the President's Council on Sustainable Development and the EPA have recognised the potential for industrial ecosystems. In the last two years, research into eco-industrial parks has been undertaken in Brownsville, Texas; Baltimore, Maryland; and Cape Charles, Virginia (Ecocycle Issue 4 1996).

2.5 Motivation for design for the Environment

There are a number of reasons why a company might add design for the environment to its list of critical activities. They include:

2.5.1 Legislative Compliance

There has been a major increase in the number and diversity of environmental regulations in the past twenty years. Companies are finding increasing costs associated with both the treatments required and the reporting necessary to comply with these regulations

An example of this, is the SARA 313 emissions report requirement is the United States. Companies must report their emissions annually of a list of

300 toxic chemicals to the US EPA under the Community Right to Know programme (Harris Corporate Environmental Policy).

2.5.2 Market Demands

Both large and small customers are increasingly demanding environmentally preferable components and products. The public is equipped with new data about emissions and increasingly intolerant of environmentally inappropriate manufacturing practices. Sophisticated customers, such as large firms and even Military and Aerospace are demanding environmentally acceptable products (American Electronic Association DFE white paper no.1).

An example is the USEPA "Environmentally Preferable Computer Acquisition Program" This program may set additional acquisition requirements for all Federal government agencies, based on environmental performance attributes that computer products must meet to be eligible for purchase by all Federal government agencies (USEPA 742-F-96-002).

Another example of this, is the AC Delco regularity compliance. This company, which provides electronics for General Motors in the US, requests its suppliers to verify that the parts supplied meet all regulation as regard environmental, health and safety (see Appendix I).

2.5.3 Sustainable Development.

Companies seek to integrate economic growth, environment, health and safety improvement in its operations for competitive advantage and long term viability. Designing for the environment will maintain the economic health and ensure sustainability of the company and natural resources.

2.5.4 Restricted Chemical Use

Toxic chemical lists, as directed by regulation (91/269/EEC) have made products restricted waste. Examples are Cadmium, Mercury and Polychlorinated Biphenols (PCB's) and more recently ozone depleting compounds. Recently, the requests for chemical content from customers contain chemicals that are not on any list but have been highlighted as potential health hazards (see Appendix I). The qualification programme for approval of a supplier in an industry with ISO 9000 or QS 9000 certification is time consuming and expensive. In order to maintain market share, re-qualification may be necessary to remove potentially restricted chemicals.

2.5.5 Future legislation

To comply with current regulation is no guarantee of avoiding future liability. An example of this is the "clean-up " of hundreds of toxic leaks from underground storage tanks in the US.

In 1982, at the Fairchild Semiconductor facility at San Jose, California, it was discovered that the underground storage tanks had leaked solvents into the nearby bore hole (Perry, T. 1993). On further investigation, by the regional water quality board, 85% of the other electronic facilities, had leaks from storage tanks. Cleaning up of these sites is ongoing, and work is expected to continue for decades. Estimated cost for the IBM cleanup is $100 million. These facilities had complied with the legislation at the time and followed the storage guidelines of fire and building codes, but were not protected from major environmental costs.

Another example is the proposed German electronics take back ordinance. If enacted, this would mean electronic manufacturers would have to take back and recycle their goods at the end of their useful life (Schreider, A. 1997).

2.5.6 Cost.

The present legislation and potential future legislation have the potential to incur major costs for electronic companies. The previous points highlight potential cost penalties, all of which have no added value to the product. Monitoring, testing and cleanups do not have a pay-back period. Costs are incurred and they cannot be recouped by any improvements in product and performance.

DFE has the potential for both cost avoidance and also cost reduction. If a company can reduce the amount of waste it disposes of, it achieves a double saving. Firstly, waste was originally a material that was bought, if re-used it can reduce the costs of new materials . Secondly, cost of disposal of the waste is avoided. Waste minimisation is the opposite of yield improvement.

2.6 Design for the Environment

Design for the environment (DFE) requires the analysis of a product's entire life cycle. Incorporating environmental considerations during the products design and development stage enhances a product's environmental performance throughout its life cycle.

A typical design project begins with a needs analysis, then proceeds through formulating requirements, conceptual design, preliminary design, and implementation. During the needs analysis, the purpose and scope of the project, and the customer needs are clearly identified. Concurrent design is used to ensure that the design project is feasible and that the product is designed with manufacturing in mind to reduce the risk of processing problems and yield issues occurring after the design stage. Total Quality Management (TQM) is a system of instilling quality into all facets of the business.

Both these concepts provide models for DFE. Appendix II demonstrates the complexity of integrating environmental issues into design. The goal of sustainable development is located at the top to indicate its fundamental importance. External and internal factors in the management of the project that shape the creation, synthesis and evaluation of a design are emphasized. The requirements are then developed which includes environmental requirements. The development team continuously evaluates alternatives throughout the design process. Environmental analysis tools ranging from single environmental metrics to comprehensive life cycle assessment (LCA) may be used in addition to other analysis tools. Successful designs must ultimately balance environmental, performance, cost, cultural, and legal requirements (Keoleian, G. et al. 1994).

The aim of DFE is to avoid the mistakes of the past, to prevent shifting impacts between media (air, water, land) and between other stages in the life cycle of the product. Another term for this is Life Cycle Design which was defined by the US EPA in their *Life cycle Design Guidance Manual* as:

"Systems-orientated approach for designing more ecologically and economically sustainable product systems which integrates environmental requirements at the earliest stages of design."

2.6.1 Life Cycle Stages of a Product

DFE should cover the environmental performance of a product throughout its life cycle. Standard life cycle stages of a product are:

1. Raw Material: This includes the extraction of raw materials and the processing into a useful form, e.g. the extraction of crude oil refining into petrochemicals; converting bauxite to aluminium.
2. Product manufacturing, processing and formulation: The manufacture of products by various processing steps and parts assembly, e.g. aluminium metal is formed into sheet and combined with other materials to make a finished product.
3. Product distribution and transportation: Transportation to distributors and from sales outlets to the end user. Includes packaging required.
4. Product use/ re-use/ service: Products sold to customers are consumed or used for one or more functions. Throughout their use, products may be serviced to repair defects or maintain performance.
5. Product disposition/disposal: Users eventually decide to retire a product. After retirement, a product can be reused or re-manufactured. Material and energy may be recovered through recycling or incineration.

2.6.2 Environmental Criteria for a Product

A designer could consider numerous potential environmental impacts for a given life cycle stage. For a DFE system to be effective, these possible combinations must be translated and reduced into a reasonable, practical set of design criteria that are relevant to the product being designed. A company can use a DFE programme to provide its product development teams with the knowledge and information needed to respond to environmental issues. This involves translating vast sets of information into a group of environmental criteria. The criteria can be driven by the specific products a company makes or general environmental criteria proposed by government agencies (Veroutis, A. et al. 1996b). The following list is a generic format for environmental criteria.:

1. Depletable material resources: The use of the earth's non renewable resources. Metals are a finite source, if recycling does not take place or if the resource is overused then it would be depleted.
2. Energy: Energy use, in addition to being a significant non renewable resource, also contributes to environmental burdens of acidification, global warming potential and smog.
3. Global Concerns: These include ozone layer depletion, eutrophication of waters and the greenhouse effect.
4. Hazardous materials risks: The use of hazardous materials in products and processes may mean releases to the environment in the form of heavy metals leaching from landfill sites or air emissions.
5. Local Concerns: Air, water emissions and solid waste residues can have a significant effect on local environments.

2.7 Tools used for the design for the environment.

Several tools have been developed to enable design and manufacturing engineers in the electronics industry to practice DFE. They can be separated into two, interrelated types of tools:

- analysis tools which support the identification of key environmental concerns caused by a particular product in all its life stages.
- improvement tools which facilitate the generation of options to reduce the environmental burden caused by the particular product in its different life stages.

DFE projects should use analysis and improvement tools in conjunction. An idealised DFE project starts with the application of an analysis tool, to identify the key environmental issues, followed by the application of an improvement tool, to generate a set of alternative product improvements, and ends with the second application of an analysis tool, to assess the impact of the alternative product improvement (van Berkel, R. et al. 1996).

2.7.1 Analysis tools

The most detailed analysis tool is life cycle assessment. This will be discussed in detail in chapter three.

Alternatives tools focus on the company rather than the product. An example is the Northern Telecom Environmental Performance Index, this index is designed to provide a consistent measure of the overall environmental performance of the corporation. It can be used to track yearly progress to environmental goals and to communicate that progress to interested parties. It does so by scoring compliance, environmental releases, resource consumption and remediation against a benchmark value (http:\\www.nortel.com).

2.7.1.2 Life Cycle Cost Analysis

Life cycle costing is the sum of all internal and external costs associated with a product system throughout its entire life cycle (Lund, R. 1978).

Cost analysis can be a most influential tools guiding decision making.

The stages that can be included in this calculation are:

- product manufacture
- transport and distribution
- consumption and support
- product collection and disposal.

Van Mier et al from Philips Electronics has proposed a calculation method which demonstrates a high correlation between life cycle costing and Life cycle assessment using a 17" computer monitor as an example. The costing is based on actual production costs for the product; costs of transportation including levies, storage; costs of consumption and support are based on energy use and cost of service outside of warranty; cost of disposal is based on costs of collection, disposal of packaging, disassembly and disposal of parts.

The life cycle assessment analysis was based on the Eco-indicator method to study the environmental profile of the monitor (see Chapter 3). The data is based on emissions due to production, transportation emissions, energy use and emissions due to incineration of the monitor as a means of disposal. In this study the relative contributions to costs and environment were exhibited. Table 2.3 shows part of this calculation.

It appears that for the life cycle costs and the Eco-indicator the production and consumption stages are the most important. In the life cycle costing calculations these two stages are almost equal in importance with 40% of the cost due to production and 50% due to the consumer stage. In the Eco-indicator calculations the consumer stage plays a very important role, amounting to approximately 80% of the total. The authors believe that the lack of data in the production stage is lowering this result and expect that the absolute value for this stage will rise with a factor of 2-3 upon completion of the data (van Mier, G. et al 1996).

	Life Cycle Cost (%)	Eco-indicator (%)
Production	38.5	18.2
Distribution	10.0	1.3
Consumption	49.4	78.5
Disposal	1.1	2.0
Total	**100**	**100**

Table 2.3 Life cycle costs and Eco-indicator results for a Monitor.

2.7.1.3 Environmental Matrices.

Moving from a set of environmental criteria to a complete DFE system requires additional steps of quantifying each environmental criterion in a format that is measurable and meaningful to the design team. This measurable format is known as an environmental metric (Veroutis, A. 1996). A simple matrix can assist the designer in defining and tracking the scope of the system.

The following matrix is based on the Canadian Standards Association instruction CSA Z762-95. It can be filled in by the design team to help identify and develop DFE environmental criteria.

	Raw Material	Manufacture/ Process	Distribution/ Transport	Use/Re-use/ Maintenance	Disposition
Depletable Material resources					
Energy					
Global Concerns					
Hazard Material Risks					
Local Concerns					

Figure 2.4 Canadian Standards Association Matrix

This simple matrix hides the vast amount of data required to complete it. In essence a complete life cycle assessment would need to be completed in order to fully understand the environmental burden associated with a new product. Designers are invariably under time constraints to develop a product and bring it to market -- before the competition does. To put the onus on them to also calculate the environmental burden of their product will meet with objections from the industry. It is not that designers are against the concept, rather the objection is that, designers must become environmental experts. Each product system contains many product life cycles within it. To examine each part would complicate the analysis.

The simplest decision can be based on the "less is better" approach. If energy use is deemed the most significant attribute when designing a monitor, then one design can be compared with another for that criterion.

2.7.2 Improvement Tools

At present the improvement tools used for DFE in the electronics industry, may be categorised as either 'design guidance' or 'design requirements'.

The design guidance tools provide the design team with strategies to improve the environmental performance of a product. These include product improvement approaches, where the improvement options are generated through the application of one of the following product improvement approaches to a reference product:

1. Alternative need fulfilment;
2. Product system life extension;
3. Selection and effective use of materials;
4. Closure of the material cycles;

5. Energy conservation (in production, use etc.);
6. Cleaner production;
7. Efficient distribution and logistics.

Another type is product improvement matrix an example of which will be discussed here in detail.

2.7.2.1 Environmentally Responsible Product Assessment Matrix.

AT&T have proposed a checklist called the "Environmentally Responsible Product Assessment Matrix" (Graedel, T. et al. 1995). This is a 5 x 5 assessment matrix, very similar in design to that by the Canadian Standards but instead of a full blown life cycle assessment, the DFE assessor studies the product design, manufacture, packaging, use and disposal stages. He/she then assigns to each element of the matrix an integer rating from 0 (highest impact or worst evaluation) to 4 (lowest impact or best evaluation). The assessor is estimating the result of a completed life cycle inventory assessment. He/she is guided in this task by experience, a design and manufacturing survey, appropriate checklists, and other information.

This assessment appears to be highly subjective, however, the authors claim, in an experiment less than 15% difference in ratings among a group of four assessors, when provided with checklists and protocols. They also claim that, rather than months for the life cycle analysis, they can complete an DFE for a product in a matter of days.

The process described here is purposely qualitative and utilitarian, but does provide a numerical end point against which to measure improvement.

Once an evaluation has been made, the overall Environmentally Responsible Product Rating (R_{ERP}), is computed as the sum of the matrix Element Values: $R_{ERP} = \Sigma_I \Sigma_j M_{i,j}$

2.7.2.2 Use of target plots on an electronic switch.

To display the overall system matrix a target plot can be used. An example of which is shown in Figure 2.6 To construct the plots, the value of each element in the matrix is plotted at a specific angle (For a 25 element matrix, the angle spacing is 360/25 = 14.4°). A good product or process shows up like a good rifle target, with all shots bunched at the centre. Bad elements are highlighted by being far removed from the target. This example is of an AT&T electronic switch, the flagship 5ESS®. From this is can be seen that pre-manufacture and product delivery are areas needing attention. (Graedel, T. et al 1996) The Environmentally Responsible Product Rating is 64%. The higher the score the better the product.

Environmental Concerns

Life cycle stage	Materials Choice	Energy use	Solid residues	Liquid Residues	Gaseous residues
Pre-manufacture	(1,1)	(1,2)	(1,3)	(1,4)	(1,5)
Product manufacture	(2,1)	(2,2)	(2,3)	(2,4)	(2,5)
Product packaging and transport	(3,1)	(3,2)	(3,3)	(3,4)	(3,5)
Product use	(4,1)	(4,2)	(4,3)	(4,4)	(4,5)
Refurbishment - recycling-disposal	(5,1)	(5,2)	(5,3)	(5,4)	(5,5)

Figure 2.5 Environmentally Responsible Assessment Matrix.

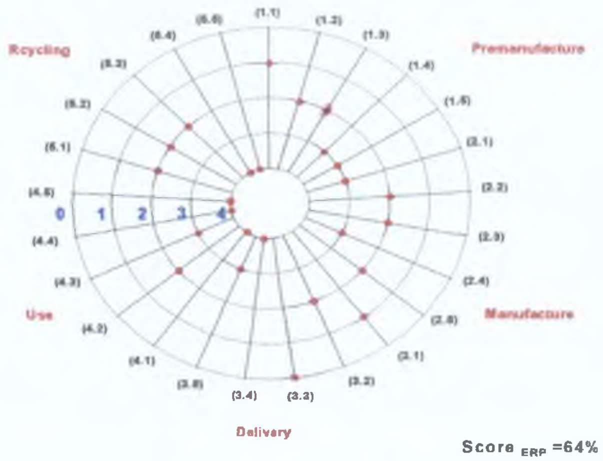


Fig 2.6 Target plot for an electronic switch.

2.7.3 Design requirement improvement tools

These tools contain specifications regarding, for instance, the use of materials and energy and the presence of hazardous substances in the final product. Most often, these design requirements are essentially inventories of blacklisted chemicals. Some examples are negative material checklists and Blueprints. Negative material checklists are normally used by original equipment manufacturers such as IBM, AT&T and Ericsson in negotiations with their suppliers.

Environmentally sound blueprints may be interpreted as negative checklists with positive features (van Berkel, R. 1996). There are very few blueprints for electronic products but the criteria for the German Blue Angel logo could be described as an example of one.

2.7.3.1 German Blue Angel

The German Blue Angel is one of the oldest and most successful eco-labelling programmes. Over 28 years, criteria were established for approximately 100 product categories and over 1000 companies were awarded the right to use the Blue Angel logo on their products (Dirksen, T. 1996).

In a survey conducted by the German Frauenhofer Institute, 67% of consumers claimed to consider the Blue Angel when making a purchase. It is also becoming a purchase criterion for government agencies. Sales to these agencies and public institutions can lake up a sizeable part of the computer companies business. For these reasons, when the ‘PC Blue Angel’ registered as RAL UZ-78, was published in 1994, the computer industry became very interested. This is the first comprehensive Eco-label for PC’s and it is likely that it may serve as a model for the future EU Eco-label for PC’s.

The "PC Blue Angel" is granted to products that are "designed to live long and with recycling in mind" (English translation of the German text in the Logo). There are approximately 65 detailed criteria, spread over the following categories:

- expandability/upgradability
- take-back and recycling commitment
- material selection
- flame retardants
- material marking
- ease of disassembly
- ease of recycling

- acoustics
- batteries
- energy consumption
- safety and radio frequency interference
- ergonomics
- packaging
- manuals

At every stage in the programme, the manufacturer must prove compliance. For example, the product in question must be completely dismantled, compliance with the criteria checked, and a 'Design for the Environment' checklist filled out (Dirksen T. 1996).

The approach is very strict and rational. The criteria themselves are also very rational and stay away from value dependant LCA's. Their most salient point is that, in the development of the criteria, industry and the ministry are invited to give their point of view on the environmental benefits and feasibility of the proposed criteria.

Hewlett Packard have pursued the use of the Blue Angel logo for their products. They commented that the criteria was extremely strict with no leeway for not meeting one of the 65 criteria. The criteria are revised every two years, which is probably sufficient for most products as it gives stability to the label, but according to HP is " very long for a high-tech fast moving PC business with typical product life times of approximately 12 months" (Dirksen, J. 1996). Perhaps HP should go back to the text on the logo "designed to *live long* and with recycling in mind" and realise that product life times of 12 months are exactly what this Eco-label is trying to stop.

2.8 Methods for improving the environmental performance of a product.

2.8.1 Product system life extension

For a sustainable development system high on the priority list is product system life extension. System life extension means designing a system with appropriate durability for its intended use. Theoretically, it is wasteful of energy and resources to produce a system to last past its useful life. An example is a plastic disposable cup. To make a cup with high grade/high density plastic is wasteful of resources. On the other hand to extend the useful life of electronic goods could have a positive impact on overall resource use, as well as reducing the quantity of waste generated (World Resource Foundation 1996).

2.8.2 Design for disassembly and reuse.

Designing a system for modular construction is key to ensuing adaptability in products with many parts, because it allows fast changing components to be easily upgraded without replacing the entire unit. An example of this is the new Apple computer: Power Macintosh 7200. This computer was developed on the lines of DFE guidelines. The company claims that the modular design will allow easy installation of hardware upgrades, such as expansion cards, additional memory and increased capacity or enhanced performance of fixed storage devices (Fiksel, J. et al. 1996).

2.8.3 Serviceability of a product

How serviceable a product is will determine its useful life. Easily repairable products rely on interchangeable and standard parts. Interchangeable usually applies to parts produced by one manufacturer, while, standardisation refers to compatible parts that conform to accepted design standards made by different manufacturers. Speciality parts require expanded inventory and extra training for repair engineers. Finally, repairable designs need proper after-sale support. Manufacturers of repairable products should offer useful information about trouble shooting, procedure for repair, tools required and the executed useful life of components and parts (Keoleian, G. 1994). Again, modular design can assist in the quick change of components. At present, original equipment manufacturers and computer manufacturers in particular have got a bad name for ‘planned obsolescence’, where no repair or service is offered after the warranty period is over. Replacement parts are not available and so the product is scrap and must be replaced.

2.8.4 Design for Re-manufacture.

This means designing products that, at the end of their useful life, they can be restored to like-new condition. A retired product is first completely disassembled. Its usable parts are then cleaned, refurbished, and put into inventory. Finally, a new product is reassembled from both old and new parts, creating a unit equal in performance and expected life to the original. Industrial equipment or other expensive products not subject to rapid change is the best candidates for remanufacture. Typical remanufactured products include jet engines, buses, railcars, manufacturing equipment and office equipment. Viable re-manufacturing systems rely on the following factors: a sufficient population of old units; an available trade-in network; low collection costs; storage and inventory infrastructure (Keoleian, G. 1994). In addition it is necessary to design for disassembly to ensure parts are interchangeable and remanufacture is cost effective. One manufacturing company stands out in the benefits achieved by remanufacture; Rank Xerox.

Rank Xerox won the 1996 waste recovery award under the European Better Environmental Awards for Industry scheme. The prize went to the company for its closed loop scheme for recovering and reusing end-of -life copiers in Europe (ENDS Report 261, 1996). The scheme was launched in June 1993, when Rank Xerox set up a dual product range; 'newly manufactured' products containing a small proportion of reprocessed parts from recovered equipment, and 'remanufactured' products comprising mature equipment containing predominantly reprocessed components and offering particularly good value in price-sensitive markets. Rank Xerox is well placed to recover redundant equipment as a large proportion of companies now lease rather than buy copiers. This means that it had its own distribution operation down to the customer, enabling old copiers to be collected when a replacement machine is delivered. The company operates three 'asset management' centres in Europe- in the Netherlands, France and Britain- for disassembly.

Components are cleaned and inspected, items within sub-assemblies that cannot be reused, are recycled where possible. In 1993, when the programme started the company was recovering approximately 30% of the 'customer out-placements.' In 1995, the recovery rate had risen to 66%, approximately 80,000 of the 120,000 copiers discarded annually in western

Europe. Of these, 60,000 were remanufactured and sold, while 20,000 were used to provide components or spares.

Design for the environment was used for their new range of products, "zero landfill"-- with all components fully reusable or recyclable. The new range appears to have posed some tricky accounting questions, alluded to in Rank Xerox's environmental report, which is likely to be faced by any business applying DFE seriously. According to the report:

"One of the more difficult issues currently being tackled by the company is the fact that developing robust designs for longer life generally leads to increased unit manufacturing costs, although the life-cycle costs are improved through the ability to reprocess parts a number of times" (ENDS Report 261,1996).

2.9 Status of Design for the Environment tools.

The degree to which DFE is increasingly represented at various conferences would indicate that this new discipline is becoming part of the business world. There are numerous computer models and software packages to aid the designer in developing a product, these include manufacturing analysis ("Manufacturing Advisor" from Texas Instruments) and process flow analysis (" Envision" Dow Chemical).

2.9.1 DFE Analysis tools

DFE orientated life cycle analysis is well represented by "EcoManager" (PIRA, Franklin Associates), "SimaPro 3" (Pre Consultants), "LCAit" (University of Chambers). These analytical tools range from spreadsheet applications to sophisticated database managers. The biggest difference between good and poor ones was the amount of data available within the software package (Mizuki, C. et al. 1996).

2.9.2 Disassembly /Recyclability Process Analysis.

These types of analyses are used to modify a system's content or manufacturing process to facilitate disassembly and recyclability of the product at the end of its life. Some tools available are; "ReStar" (Green Engineering Corporation) and "Diana" (POGO International). These tools are mostly library based where a solution is created to a user's problem, using pre-defined solutions from libraries. Some issues arise when the library has no information on the problem posed and so, generates the same solution for each problem (Mizuki, C. et al. 1996).

In a survey of current practices in DFE carried out by Lennox, Jordan and Ehrenfeld comprehensive analytical software was not widely used. The results of the survey show:

- 87.5% of firms developed in house DFE programmes,
- 94% of DFE's incorporated checklists,
- 69% included guidelines,
- 56% included design constraints,
- Inventory data and impact data, as used in LCA were included in only, 37.5% and 31% respectively.

DFE appears to be in the very early stages of integration in designing of products. There are few firms with formalised DFE and those that did were less than two years old. There was a diverse set of approaches used as a result of the uncertainty of how to design for the environment and there were no proven set of DFE practices. The majority were using methodology that was developed in house and not bought into the company (Lennox, M. et al. 1996).

2.10 Issues in DFE.

The most important criterion in DFE is that it must cover all aspects of the environmental interactions of a product over its entire life cycle. Communication is important to the success of the project. The cross functional nature of the environmental issues requires lines of communication between designers, sales and marketing, environmental and material experts and the suppliers themselves. (American Electronics Association, White Paper no. 1 Design for the Environment).

There are a number of obstacles to DFE, a major one is the lack of a common language. The lack of standard criteria means that DFE from one product to another cannot be compared.

The issue of trying to balance one environmental burden against another is difficult. Determining if 10 ppm of heavy metals is greater or less than the use of 1kwatt of energy cannot be answered as present. The concept of less is better can move the process along without these value judgements.

If DFE is to be used as an internal tool only, then each user must understand what it means to their operation. Expertise is needs as to what impacts are most critical from an environmental standpoint and further knowledge on what is feasible from an economic viewpoint.

2.11 Recommendations

Many companies have published great success stories regarding their design for the environment programmes. Examples shown here are Apple, Rank Xerox, HP.

A number of companies start small with their endeavours, the following is modest starting point proposed by the *American Electronics Association*, in their White Paper No. 1 "Design for the Environment" to suggest to companies how to begin DFE:

- Obtain the commitment of senior management first.
- Integrate the team concept to bring all players into the arena.
- Implement pollution prevention measures. A waste management system with a review of where each waste stream comes from, is a good starting point. From here it can be highlighted which processes produce the most/ toxic waste. Design products that produce less waste over time and eliminate the use of hazardous materials.
- Design for refurbishment: Make products so that they can be taken back and refurbished to be reintroduced into industry.
- Design for disassembly and recycling. Although this may not appear to be a viable or practicable option now. By the time these products are ready for disposal, the infrastructure may develop. Critical European markets may require take back, disassembly and recycling of products.
- Quantify environmental costs associated with specific processes and products. Items such as energy, waste, bag house filters, waste water treatment are normally embedded in overhead or facilities costs. By segregating as product specific, they are more likely to get more focus and they can then be shown as improvements with reduction in costs to the bottom line.
- Review specifications and vendor requirements to ensure that no unnecessary environmental impacts are included in the supply chain. For example, a flammability specification which necessitates the use of brominated phenyl oxides.

2.12 Conclusions

DFE is a new field for electronic industries. The impacts of take back legislation and waste issues cannot be overcome with business strategy alone. As manufacturers become more environmentally sophisticated they go further toward the beginning of product development and eventually get to designing the product with the environment in mind because the whole process starts there. The phases of environmental awareness closely follows legislation.

The first phase, where manufacturers design a product and a process to produce it and only then concerns itself with such considerations as getting environmental permits and how to dispose of the waste. This is equivalent to the 'end-of-pipe' regulations of the seventies.

The second phase, where designers consider some environmental issues and seek to minimise impacts. For example, by specifying less polluting chemicals or processes. This is equivalent to 'pollution prevention' legislation.

The third phase is the adopting of DFE. No product leaves the design department until all its impacts have been taken into account in the design. This is the sustainable management of natural resources.

The concept of industrial ecology closes the loop between material use and reuse, this means looking at the system as a whole. Business collaboration may be required to achieve the aims of sustainability. Using one process waste as another raw material and using less materials overall.

There are limits to what DFE can accomplish in the broader cultural aspects of society. Designers fulfil a need of society but are not responsible for the ethics of society. The consumer has a large part to play in this concept. Cultural factors in the purchasing and disposal of goods must change for this to move forward. Attitudes to how the products are used in society and the types of products in use requires modification. If the attitude of the 'latest and the greatest' prevails and remanufactured products hold the status of 'second hand' little or no improvements can be made in the obsolescence of products and therefore, reuse of materials.

No analytical tools will provide all the answers to designing a product either from a standpoint of manufacturability, cost or environment. Checklists and matrices examined here are not difficult to use but must be compiled carefully so that they do not demand excessive time from the designers to complete. There is a concern that they may interfere with creativity because designers rely on them exclusively to address environmental issues without considering which items in the list are most appropriate for their specific project. The ideal tool would have the intelligence to allow the designer to make choices and understand the trade-offs at each stage in a seamless and transparent manner. These tools are not yet available but are rapidly being developed. The techniques that have been developed and are in development will assist designers in examining the environmental aspects of products over the total life cycle

Environmental criteria must stand beside other product development requirements such as cost, performance and function. It cannot be the overriding requirement in a manufacturing systems with other objectives for the company as a whole. Life cycle Cost analysis combined with environmental analysis could be a key linkage between these objectives.

The difficulties of DFE are that it is impossible to know what the technology of recycling or the state of the environment will be in, for instance, 5 years time.

Designing for remanufacture is an area where significant improvements have been made, such as Xerox, IBM and Sony.

Key improvements have also been made in designing for recycling by the introduction of reduction in material variety, using recycled materials and identifying plastics. Recycling also includes design for disassembly. The introduction of modular design and using compatible materials so that recycling can be economic and efficient are examples of this.

The recommendations from the American Electronic society, may not provide quantum leaps in environmental performance improvement but a DFE programme can slowly but continuously move in the same direction. These practices will not close products' material cycles, but they will give companies time to reconsider and adapt to a different lifestyle, or to develop alternative materials that will have a closed-loop cycle and minimise the environmental degradation caused by their products.

DFE is still in the infancy stage of development but its continuous development and implementation has the ability to make significant inroads towards a sustainable future.

Life cycle assessment has been called the ultimate design for the environment tool but in actual fact it is a decision support tool used in the analysis of a product. It is an analysis tool which can quantify the emissions, materials and energy that a product uses during its life cycle. These inventories can then be examined for environmental impacts and hence improvements can be made. Its use as recommended by governments and environmental bodies will have implications for all manufacturers and so it will be discussed here in detail in the next chapter.

Chapter 3 Life Cycle Assessment

3.1 Introduction

Life Cycle Assessment examines the environmental impacts of a product or process from the raw material extraction, to manufacturing, use and disposal. By quantifying the environmental impacts of a product system from cradle to grave, Life Cycle Assessment (LCA) can generate ideas for reducing these impacts by means of process modifications, product redesign, material substitution or selection of an improved waste management option.

LCA contains four separate components, these are: Goal and Scope Definition; Life Cycle Inventory Analysis; Life Cycle Impact Analysis and Life Cycle Improvement Analysis. Figure 3.1 demonstrates the components of LCA and some of its intended uses. This chapter will examine each of these components in turn and the standards proposed by international organisations. The issues effecting the use of LCA and the status of implementation will also be examined.

Life Cycle Analysis and Response and Environmental Profile Analysis were some of the original terms used for this technique. In essence, they mean the same thing, in that they examine a product from raw material input to disposal. In the context of this thesis, the acronym LCA will stand for Life Cycle Assessment only.

3.2 Background

The first life cycle assessment of products was initiated in 1969. The concept is attributed to Harry Teasley, then with the Coca-Cola company (Hunt, et al.1992). Under the Coca-Cola sponsorship, a life cycle study of several different beverage containers was conducted by Midwest Research Institute (MRI). The purpose was to compare different containers to determine which produced the fewest effects on natural resources and the environment. Only issues that could be quantified and that data was available for were considered. What was reported was the quantities of various effluents and the amounts of natural resources consumed. The result was an accounting of things that create a burden on the environment without actually assessing those effects directly.

Between 1970 and 1975 several LCA studies were conducted at MRI by Hunt, Sellers & Franklin and the research protocol was developed. After 1975, the interest in comprehensive environmental studies generally decreased due to complexity and cost. Energy was the main interest and the energy portion of the LCA methodology was used.

In the 1980's, there was little public interest in LCAs with the shift in emphasis to hazardous waste. In 1988, in the US, solid waste became an issue with the overfilling of landfill sites and the increasing amount of solid waste generated. This along with other environmental concerns revived the concept of LCA. Industry, government and academic institutes looked on LCA as a possible major tool in decision making.

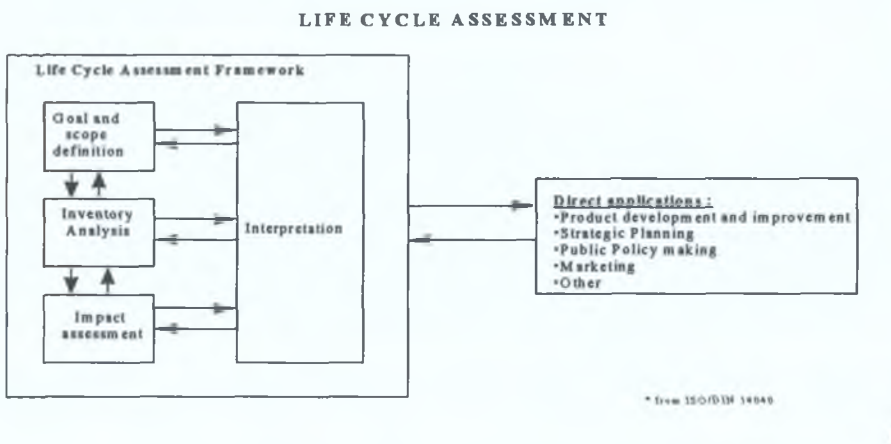


Figure 3.1 Components of Life cycle Assessment. (ISO)

3.3 Motivation

Essentially, a life cycle assessment attempts to identify and quantify all the environmental impacts that could be attributed to any aspect of the production, use or retirement of a product or process. It attempts to assess these impacts so that different results can be compared, and finally in the case of the analysis of a design option, it tries to evaluate the potential for improvement (Choi. 1995). The motivation for LCA stems from the desire to be able to fully understand the environmental implications of design and product choices, and to be able to compare two or more designs, products or activities. In a recent study carried out for the European Commission, firms surveyed cited improved competitiveness, a better understanding of environmental issues and innovation as the key benefits of LCA. Many

European firms report that waste management regulations and competition are driving LCA activity (Ecocycle Issue no. 5 1997).

The reasons for carrying out an LCA can also vary.

- It might be carried out by an industry sector to enable it to identify areas where improvements can be made.
- An LCA may be intended to provide data for the public or for governments to aid in decision making.
- In has been widely suggested that LCAs are ideal for supporting eco-label award schemes which has been set up to label products with reduced environmental impact (Council regulation EEC No. 880/92).
- With the increasing use of LCAs, a number of companies have cited LCAs in their marketing to support claims that their products are '*environmentally friendly*' or '*superior*'. These claims along with inappropriate methodology have made requests for the standardisation of methods in the conducting of LCAs

3.4 The Stages of the Life Cycle.

The life cycle of a product is typically understood to contain the five stages of raw material acquisition, material processing and manufacture, distribution and transport, product use and finally retirement.

The inputs to these stages involve raw materials, energy, (air and water, also.) The outputs, include the principal products, water effluents, airborne emissions, solid waste and the other environmental releases (SETAC Technical Framework for LCA). These stages are represented by a schematic diagram in figure 3.2.

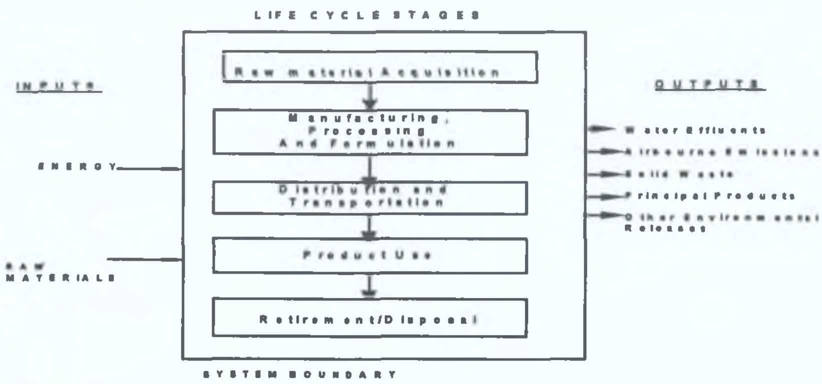


Figure 3.2 Life Cycle Stages (SETAC)

3.5 The Components of Life Cycle Assessment

The components of LCA are goal and scope definition, inventory analysis, impact analysis and improvement analysis. Figure 3.3 shows the linkage between these components.

3.5.1 Goal and Scope Definition.

In principle, the first need when initiating an LCA is a clear statement of purpose. What the objective of the study is and what decisions will be based on the results of the LCA.

According to ISO the goal of the study shall unambiguously state the intended application, including the reasons for carrying out the study and the intended audience.

ISO 14040, in their scope specify the items that should be considered and clearly described, these include:

- the function of the system and the functional unit;

- the system to be studied and the system boundaries;
- allocation procedures;
- the types of impacts and the methodology of impact assessment and interpretation to be used;
- data requirements;
- assumptions and limitations;
- critical review and the type of the report .

ISO also state that the

"scope should be sufficiently well defined to ensure that the breadth, the depth and the detail of the study are compatible and sufficient to address the stated goal."

3.5.1.1 Function of a system and functional unit.

The scope should clearly specify the function of the system. One of the first things early LCA practitioners concluded was that it was almost impossible to make meaningful comparisons between unlike materials or products - the 'apples and pears' problem. Therefore, focusing on the function served by a product or system. For example, the function of a photocopier is to produce printed copies. The functional unit may be: one copier life time use - as defined by the number of copies the product was designed to produce during its life (Calkins, P. 1996). The functional unit of an inkjet print cartridge could be the portion of a cartridge corresponding to 100 printed pages with an average print coverage of 5% black ink (Pollock, D. 1996). In the second example here, it would be quite easy to compare different types of printers, whereas, in the first example further details would be required to compare different types of photocopiers.

3.5.1.2 System and system boundaries

Setting the system boundaries makes the LCA both manageable and meaningful. The system boundary defines what components and operations are to be inventoried and assessed. These boundaries are usually depicted in process flow-sheets that show the main sequence of production; from resource to product to waste. The system must also include energy and ancillary materials that support the main production, and the production of the ancillaries themselves. The whole life cycle flow-sheet resembles a tree with many roots and branches. Some may be interdependent, complicating the analysis. Appendix III shows the system boundary of an inkjet printer cartridge for the purpose of LCA.

An example of the importance of system definition is given by Dr. Ian Bousted (ENDS report 188) who has compared several LCAs estimates of energy consumption in the production of one kilogram of aluminium hot metal from bauxite.

The estimates ranged from 0 MJ/kg to 371 MJ/kg. The lower figure although seemingly nonsensical was correct for the system as defined. In this study the system boundary was defined as a national boundary, through which aluminium metal was imported ready- smelted. This does not mean that one system was 'wrong' and the other 'right'. What mattered, was that the system was defined so that it answered the questions posed by the user.

3.5.1.3 Allocation Procedures

Allocation procedures must be used where a system has more than one product. Secondary products are not of direct interest, but their production contributes to environmental impacts. Allocation of the environmental impacts is carried out by partitioning burdens between the product of interest and co-products. This can be handled by breaking down a system into a series of sub-systems, each of which produces a single defined product. When added together, the co-product sub-system should have the same characteristics as the whole system. For example, in the refining of crude oil there will be numerous hydrocarbon fuels and petrochemical feedstocks. One method is to allocate the burdens of the refining and upstream processes based on calorific values of the different products. Another, is to allocate burdens for co-products based on their comparative masses.

3.5.1.4 Data Quality requirements

The issue of data quality requirements is the cornerstone of LCA. Three major aspects to data quality are recognised, all of which must be known about data being used in the study.

Time relation: how old is the data and what time period does it cover.

Geographical coverage: where the data comes from, whether it's site specific or industrial averaged.

Technology coverage: Nature of the technology mix - Best available technology or worst operating unit.

Other aspects, such as the precision, completeness and sources of data and the consistency and reproducibility of the methods used throughout the LCA should be specified (ISO 14040).

3.5.2 Life Cycle Inventory Analysis.

After defining the goal and scope of the study life cycle inventory analysis is carried out. In this analysis, life cycle inputs and outputs of the product, process or activity are catalogued and quantified. This includes energy and raw material requirements, air emissions, waterborne effluents, solid waste and other environmental releases. For example, the life cycle inventory analysis of a washing machine shows that the majority of the environmental impacts occur during the use stage of the product. (Appendix IV Inventory Analysis of a Washing Machine).

3.5.3 Life Cycle Impact Analysis

This component attempts to weigh the various numbers generated in the inventory phase based on the relative importance of the environmental effects that they quantify. The concept is not well defined at present. The problem is that the impacts are difficult to interpret. The subjectivity of the relative importance of the environmental effects, combined with the subjectivity of the methods for reducing the numbers from the inventory phase into an overall number given the relative importance, combines to give a very indistinct result (Spicer, A. 1997). Considering the washing machine form the previous example, impact analysis would need to determine if the use of 20 litres of water had an environmental equivalence as 1 kg of solid waste generated.

3.5.4 Life Cycle Improvement Analysis.

This is a systematic evaluation of the needs and opportunities to reduce environmental burden. This analysis may include both qualitative and quantitative measures of improvements, such as changes in product, process, and activity design. These improvements can be based on the knowledge gained from the first two components. Using the same example as above, if water consumption is defined as a major environmental impact, greater improvements to the life cycle can be made by designing a washing machine that uses less water rather than designing efforts to improve the manufacturing stage of the washing machine.

Figure 3.3 Life cycle Assessment Components.

3.6 Life cycle assessment Standards

There are five main standards initiatives for LCA (Table 3.1). SETAC (the Society of Environmental Toxicology and Chemistry) were the first to publish, with the LCA Code of Practice in 1993. In 1994, the Canadian and French standards authorities, CSA and AFNOR, followed suit, with a strong SETAC flavour to both. ISO (International Standards Organisation) and SPOLD (Society for the Promotion of Life Cycle Development) developed programmes about the same time; these two remain unfinished. ISO has a first draft out for review, but the 14040 LCA series will not be published in entirety until 1999. SPOLD expect to release by 1997. It is likely, when this happens that national agencies will adopt ISO 14000, AFNOR have already announced this, and SETAC's guidelines will become redundant.

3.6.1 SETAC

First published in 1993, *Guidelines for Life Cycle Assessment; A 'Code of Practice'* is a culmination of a collaboration between SETAC and some major industrial companies (Eastman Kodak, 3M, Proctor & Gamble, Coca Cola and some others) to produce a set of recommendations for how best to go about performing an LCA. The guidelines consider data quality, LCA applications and limitations, presentation of data and peer review. This standard is not a standards in the traditional sense; it is more of a guideline. It is not legally binding and does not have to be followed in its entirety.

BODY	COUNTRY	CURRENT STATUS	FINAL VERSION AVAILABLE
SETAC	World Coverage	Guidelines available now	1993
Canadian Standards Association	Canada	Guidelines available now	1994
AFNOR	France	Guidelines available now	1994
ISO	Support from over 40 countries	Draft for comment available now.	First draft available now. Final publication of full 14040 set expected 1999.
SPOLD	World wide coverage	Paper version complete	Available 1997.

Table 3.1 Life cycle assessment standards

3.6.2 ISO 14000 series

ISO's LCA standards - the 14040 series - are a subsidiary to the 14000 series of standards for environmental management systems. Fig 3.4 describes the 14000 series of standards.

The organisational side of ISO 14000 (the left side of fig 3.3) is based on the ISO 9000 series for quality management systems. Both define how a company should organise itself, in the 9000 instance to guarantee quality, in the 14000 instance to guarantee compliance with environmental laws.

When the standards differ, is that, 9000 is both an internal tool, to improve in-house management and also, used externally, to demonstrate that it is a quality company. The 14000 series is different in this respect and ISO recognises that

" This (ISO 14000) is a more complicated undertaking and could cause many to conclude that it will be more practical as an internal management tool."

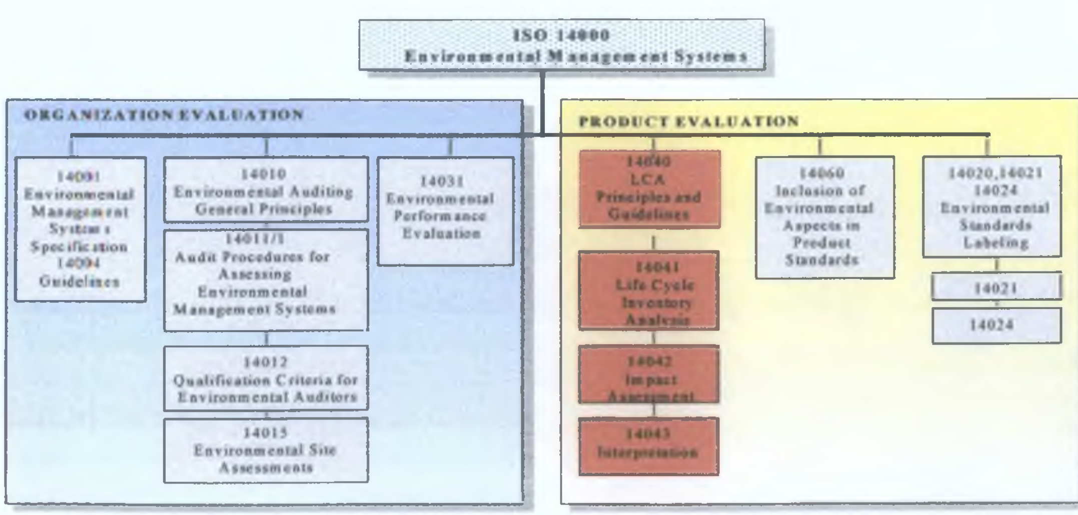


Figure 3.4 ISO 14000 series of Standards

3.6.3 ISO standard 14040

The ISO document recognises that LCA is still at an early stage of development.

"Some phases of the LCA technique such as impact assessment are still in relative infancy. Considerable work remains to be done and practical experience gained in order to further develop the level of LCA practice. Therefore, it is important that the results of LCA be interpreted and applied appropriately".

ISO goes on to stress the limitations of the technique, which include assumptions made, lack of reliable data and the nature of choices may be subjective.

ISO sees the direct applications for LCA as:

1. Product development and improvement;
2. Strategic planning;
3. Public policy making;
4. Marketing .

The final report must be fairly and accurately reported to the intended audience. Emphasis is placed on the transparency of the methods and the data. There are two types of report depending on the type of LCA. An internal LCA which would be used by a company to improve the environmental performance of the product. In this report the results, data, methods, assumptions and limitations must be transparent. An external LCA could be used to set government policy, here a third party report must be published which must include all the aspects used in preparing the LCA and include a critical review by an environmental 'expert'.

There appears to be two sets of standards here.

The first type; for companies who will use LCA internally. The idea that this will exclusively be used for internal use and that the company will not then publish papers or highlight their achievements in improvements is naïve. Reports will be published without the data transparency and with no requirements to verify the claims. They will achieve more credibility by their methods being according to ISO standards.

The second type; for any other organization which might question the claims of products or might question the status quo, then these LCAs must be exhaustively documented and put forward for complete critical review. There is high cost associated with this approach and they are much easier to criticize with the transparency required.

It is understandable that companies would not wish to made their data known to competitors or environmental protection agencies, but It is counterproductive that an international standard can have two levels.

3.7 Developments in Life Cycle Impact Assessment

Separate standards are planned for Life Cycle impact assessment. The development of these standards is still in an early phase and there are no publicly available documents yet. The following are proposed by various publications in the literature (LCANET, SETAC and CML)

Five elements have been distinguished in the impact assessment:

1. Definition
2. Classification
3. Characterisation
4. Analysis of significance
5. Evaluation

The National Reuse of Waste Research Programme (NOH) of the Netherlands have sponsored a project to develop a method to measure the environmental impacts of products or processes called "Eco-Indicator 95."

3.7.1 Definition

In the definition phase, the impact categories are chosen. In the Eco-indicator system, the environmental impacts are defined as:

Environmental effects that damage ecosystems or human health on a European scale" The categories chosen are:

- Greenhouse effect. The anticipated temperature rise as a result of the increasing concentration of gases that restrict heat radiation by the Earth.
- Ozone layer depletion. The increase in ultraviolet radiation on Earth caused by high altitude decomposition of the ozone layer.
- Acidification. Degradation of forests in particular by, for example, acid rain.
- Eutrophication. The disappearance of rare plants that grow precisely in poor soils, as a result of the emission of substances that have the effect of a fertiliser and the changes in aquatic ecosystems.
- Smog. The problems for people with weak airways (asthma patients) caused by the high concentrations of low- level ozone or by dust and sulphur compounds.
- Toxic Substances. Substances that are toxic other than as described above, e.g. heavy metals, carcinogenic substances and pesticides.

What are not included, are the industrial hygiene effects of toxic substances, depletion of raw materials and quantity of waste.

3.7.2 Classification

In this stage, all the impacts form the life cycle inventory table (i.e. the inputs and outputs from the studied system) are attributed to the impact categories. For example, impacts that contribute to the greenhouse effect may be grouped together, as are impacts that contribute to ozone layer depletion. Impacts that contribute to more than one categories are listed more than once (de Haes, U. 1996).

3.7.3 Characterisation

In the characterisation stage, quantification, and aggregation of the impacts within the impact categories takes place. This means an effective score must be produced. It is not sufficient just to add up the quantities of substances involved without applying weightings, since some substances may have a more intense effect than others. In the table below NO_x and SO_x contribute to acidification , SO_x has a more intense effect than NO_x and so the weightings are X1 and X0.7 respectively. The table below gives an example of this calculation for a small part of the inventory table. It shows the number of impacts (airborne emissions) resulting from the manufacture of polyethylene. The actual emissions are multiplied by the weighting factor before they are added. The bottom line - the effect scores - gives the result of this operation. Appendix V demonstrates classification and characterisation stage by comparing and contrasting paper and polyethylene.

3.7.4 Analysis of Significance

The analysis of significance interprets the effect score produced in the characterization stage. Interpretation depends on two factors:

1.)The relative importance of the effect compared to the size of the other effects. In the table above, it is important to see whether the greenhouse score of 1.792 refers to an extremely high or an extremely low effect level.

2.)The relative importance is attached to the various environmental effects.

The effect score can be normalised, which means the results from the characterization are divided by the actual or 'normal' effect. This could be the predicted magnitude of the given impact category.

Eco-indicator developed an inhabitant equivalent for the normalisation step, i.e. the environmental effect that the average European person causes in one year. The effects are now compared on the scale of inhabitant equivalents. (Appendix VI Normalisation stage for a paper versus polyethylene).

Emission	Quantity (kg)	Greenhouse	Ozone layer Depletion	Human Toxicity	Acidification
CO_2	1.792	x 1			
CO	0.000670			x 0.012	
NO_x	0.001091			x 0.78	x 0.7
SO_2	0.000987			x 1.2	x 1
Effect Scores:		1.792	0	0.00204	0.0017

Table 3.2 Characterisation of Polyethylene. (Eco-indicator 95)

3.7.5. Evaluation

Normalisation reveals which effects are large and which are small in relative terms. However, it does not yet say anything about the relative importance of the effects. Evaluation consists of ranking and weighting the results across different impact categories. In the evaluation method, a different weighting method may be used.

In the Eco-indicator project the weighting factor are determined by the "Distance-to- target" principle. The underlying premise is that there is a correlation between the seriousness of an effect and the distance between the current level and the target level. Thus if acidification has to be reduced by a factor of 10 in order to achieve a sustainable society and smog by a factor of 5, then acidification is regarded as being twice as serious the reduction factor is the weighting factor. Appendix VII is the evaluation of paper versus polyethylene.

The final question is ; how can such a level as the target level be defined?

Appendix VIII Eco-indicator weighting principle shows how the impacts, effects, damage, valuation and the eco-indicator values are assessed.

3.8 Issues in the use of LCA

There are three important barriers to the use of LCA.

The first is data lack of appropriate data. This includes the standardisation of the databases and the methodology of collecting data and the use of the data collected.

Secondly, their characteristics of high costs and complexity. The costs involved are prohibitive for smaller companies. Estimations of the cost of a complete LCA are £50,000 to £100,000 (LCA Sourcebook). The complexity is demonstrated in the example of an LCA of an Inkjet cartridge (Pollock. D. 1996). The data gathering phase lasted over four months with more than 1,100 processes modelled. No indication is given of how many man hours this involved.

Finally, the issue of transparency and credibility are barriers to the use of LCA. Estimates suggest that 80% of LCAs conducted for or by businesses do not enter the public domain (ENDS Report 264 1997). For a good many that have been published, crucial data or underlying assumptions have been withheld by the sponsors. An example of this being the comparison of concrete and PVC pipes funded by the Dutch concrete pipe manufacturer which came out in favour of their own products (ENDS report 262,1997). This is by no means unusual. Many published LCAs appear to have been carried out in the hope that they would provide a competitive edge for the sponsor's products, stave off legislation or address criticisms which threatened to damage a products image with consumers (ENDS Report 233, 1996). This point is poignantly put by Milieu Defense, the Netherlands (LCA Sourcebook).

"The outcome of the LCA is the result of the inputs. The inputs are a result of the preferences of those who are paying for the study."

2.8.1 Issues in the Electronic Industry.

The electronics industry has been slow in taking up LCA and some have rejected the relevance, feasibility and practicality of full LCAs on complex electronic products due to the problems of data availability, cost and time constraints.

The trend is for the use of "streamlined" LCAs by limiting life cycle stages (e.g. raw material extraction and/or impact categories). Reducing the stages and impacts is one way of making LCA affordable and relevant to the company's decision making process. These include the EC sponsored Electrical and Electronic Products LCA (ELLCA) project, where the goal is to develop an information base of materials and processes and devise a standardised LCA methodology. The industry is also supporting a project to prepare a standard format for disclosure of environmental information to enable customers to compare products made by different firms (ENDS report 264 1997).

Companies are increasingly including their suppliers to collect life-cycle information for product decisions. For example, IBM has hired consultants to work with their principal suppliers to collect life-cycle information on materials the company uses (solvent-based paints versus powder coatings, for example). In this fashion, the company uses LCA as an overall guidance framework for choosing materials and technologies (Sharpiro, K. 1997).

Nortel (Northern Telecom) and Environment Canada have embarked on a co-operative project using LCA techniques to identify improvement strategies in the design, manufacturing, distribution and end-of-life of a telephone. The green telephone project will use LCA to identify the largest contributors (processes, materials or components) to the overall environmental impact of the product. It will also characterise and quantify the expected environmental benefits of alternative design, manufacturing, distribution and end-of-life changes (Noble, D. 1997).

3.8.2 LCA for Eco-labelling criteria.

The Eco-label award scheme has been set up to label products with a reduced environmental impact. The scheme is based on Council Regulation (EEC) No. 880/92 of 23rd March 1992. The label is awarded to those products independently assessed as environmentally the best within their product range. Criteria for a product group are developed by the application of LCA. A single set of criteria for Eco-labelling is then agreed, to reduce the key impacts that have been identified. From the commission's point of view, there is a continued commitment to LCA as a principle of Eco-labelling. However, a selection of consumer goods producers have begun lobbying against LCA, stating that it is too complicated, too expensive and too time consuming (ECO-site March 97)

3.9 Recommendations

Standardised methods of conducting LCA are needed to deal with the issues mentioned. It was hoped that the ISO standard 14040 would deal with this issue. From the present draft is has made the process worse by having a two tiered approach; one for internal use and one for external practitioners. Various software packages are on the market for this purpose, including Simipro, TEAM, Eco balance and others.

The areas of data availability and quality are highlighted. Some projects underway to develop data sets are the Eco-indicator project and the Life Cycle Assessment database (USEPA Dept. of Energy). This project aims to create a range of software, data formats and databases that will standardise and reduce the cost of LCA to industry.

To increase the use of LCA within the electronics industry the streamlined approach to LCA should be adopted. This concept is gaining acceptance by both SETAC and the USEPA who have projects underway (Ecocycle Issue No. 5 1997).

Included in streamlined LCA is that the scoping phase of an LCA is used to define the boundaries of the studied system so that affected processes and only affected processes are studied. The LCA technique can therefore be applied to discrete electronic components and technologies.

3.10 Conclusion.

From the foregoing it could be concluded that LCA is nowhere near the point where it could be described as an environmental design tool for industry in general or the electronics industry in particular.

Its use for policy makers is plagued with the issue of methodology and data quality. Marketing is an area where the most attention has been given but more in negative claims about other commodities and preference for the status quo. The Environmental Directorate XI is believed to favour the use of LCA as part of its efforts to promote more sustainable consumption patterns.

LCA on its own is not a decision making technique, rather it can give direction on what decisions to make. Streamlined LCAs are in use in the electronics industry to make improvements to the products over the entire life cycle. This is a response by the industry to attempt to use the concept of LCA despite the difficulties of implementation.

Chapter 4 Electronic Goods Recycling.

4.1 Introduction

Over the past three decades there has been an exponential growth in the manufacture and sale of business and household consumer electronic appliances. Take for example, the average kitchen 25 years ago. The main electrical appliances were: refrigerator, cooker, radio and probably a washing machine which was taken out one a week. Today, that same kitchen will probably have: television, microwave oven, toaster, coffee machine, washing machine, tumbledryer, freezer, dishwasher, hairdryer, and telephone.

Equally in offices and industry, business has come to rely on electronic and electrical equipment. Computer systems, photocopiers, printers, electronic cash registers, bar code readers and security systems are requirements for business (World Resource Foundation).

Rapid advances in technology have led to better, smaller and cheaper products. This in itself causes another problem in that items are seen as disposable and become obsolete very rapidly. Industry analysis gives every indication that the trend toward fast introduction of new electronic products will continue (Minnesota OEA).

The benefits to both business and household consumers are many. However, there are also new challenges and responsibilities in managing these products at the end of their useful lives. The reasons for recent interest in electronic waste is that it contains toxic materials, is an increasing waste stream and in essence buries valuable raw materials which are then removed from the pool of available resources for future generations (Dillon, P. 1994).

4.2 Electronic Appliances in MSW.

The estimated quantities of Electronic appliances in waste varies considerable from country to country. The suggested figure is approximately 1 percent of municipal solid waste (Suzuki, Y. 1996.) (Minnesota's Office of Environemntal Assistance 1995).

The World Resource Foundation, suggest that no accurate figures exist, but some estimates are that in 1992, 2-3 percent of the entire European waste stream, amounting to 4-6 million tonnes of waste, came from electrical and electronic equipment. Another concern is that these figures are expected to rise dramatically as more electronic equipment in the consumer phase becomes obsolete. What is even more alarming is that some studies suggest that over 75 percent of retired products are in storage (Pitts, G. 1996). If these stored items were to be disposed off as municipal solid waste (MSW) this would have a significant impact on the percentage waste in these sites.

4.3 Composition of Electronic goods.

The term electronic goods refers to a vast and very diverse range of products from small appliances, such as a mobile telephone to large, complex computer systems. This diverse product range contains different materials in different combinations. This causes difficulties to arrive at any general rules on their handling, transport, storage and recycling or disposal. The following figures show the variety of materials involved and also show differences in composition of the same products. Figure 4.1 is from the Mann organisation who are an electronic equipment recycler in the UK. The company recycles products from approximately 100 organisations, including IBM, HP, Sony, Panasonic and Hitachi. It is assumed that their data is based on actual results from their company.

Figure 4.2 is the material distribution in electrical and electronic waste based on a prediction of the European waste streams for 1998.

Figure 4.3 is a composition analysis of various electronics by L.G. Scheidt and S. Zong. (1994).

The fact that these statistics are taken from different sources, over different time scales and for different reasons means that they cannot be compared exactly. What can be stated is that, taking an example of a PC system:

- The largest percentage by weight is made from ferrous metals (32-40%)
- Plastics comprise between 8% and 22%.
- Glass varies least with between 15 to 19%.

The content of the other materials varies probably due to their category definition. For example, it is conceivable that the Printed Circuit board category contains cardboard, low grade electronics, precious metal bearing waste and non ferrous metal.

The products with the most wide variety of materials is a computer system and the least is a telephone.

Domestic appliances contain a large percentage of ferrous metals (51%) and telephone equipment are mostly made from plastic.

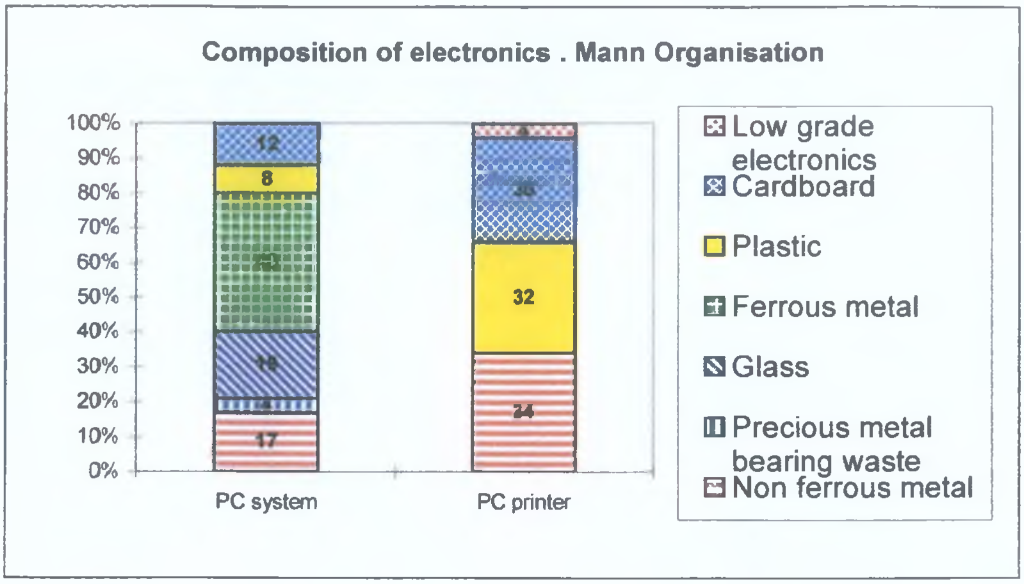


Figure 4.1 Composition Of Electronics (Mann Organisation)

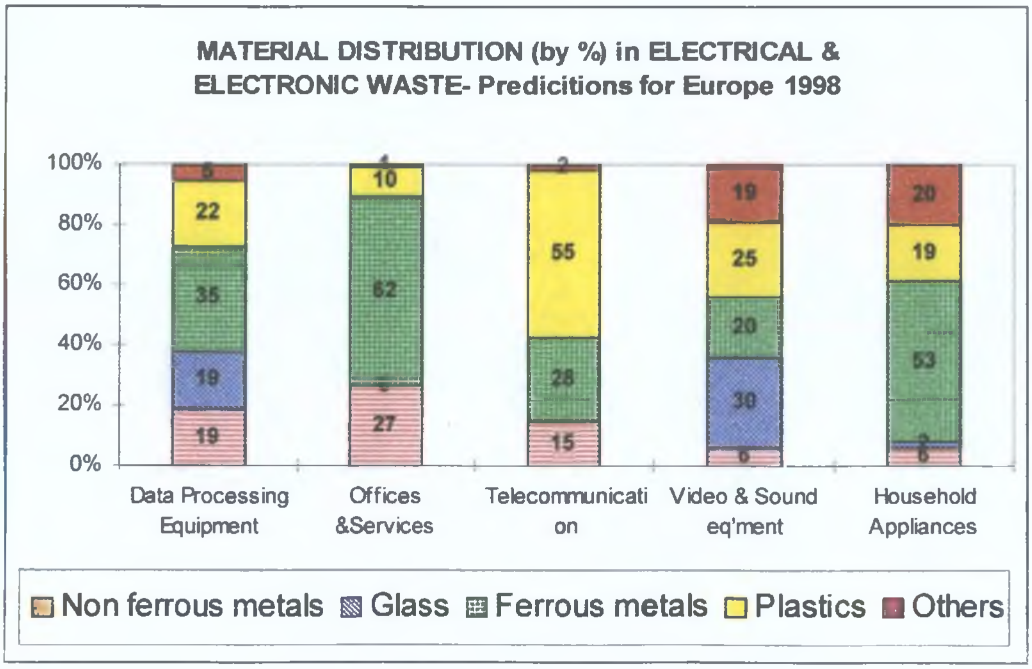


Figure 4.2 EC Priority Waste Stream on waste from electrical and electronic equipment.

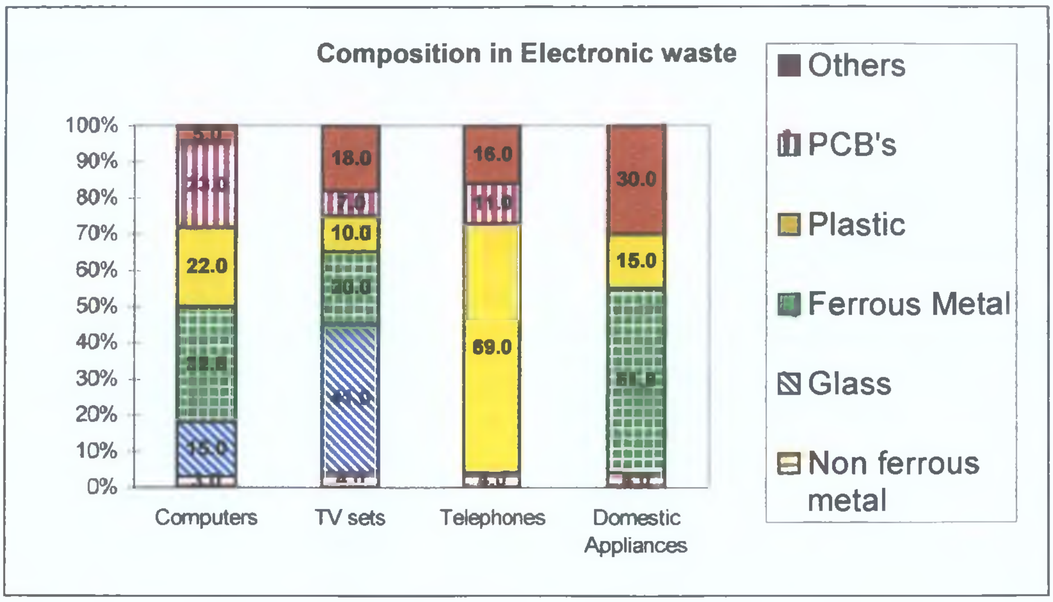


Figure 4.3 Composition Of Electronic Waste

4.4 Hazardous materials in electronic appliances and alternatives suggested.

With the amendment to the European waste directive (91/956/EEC) there are strict guidelines on what can be regarded as non- toxic waste suitable for disposal in municipal solid waste (MSW) facilities. Several organisations have published reports on the hazardous components in electronic goods.

4.4.1 Lead and Cadmium

A study carried out in 1986 in the United States, (January 1989, U.S. EPA/Franklin and Associates) identified that 65 percent of the lead was from lead -acid batteries in municipal solid waste (MSW). Consumer electronics accounted for 27 percent of lead, almost all of which was attributed to cathode ray tubes (CRTs).

The lead in CRT's, which are used in colour television sets and computer monitors, comes from the front glass panel which contains 2% lead and the funnel glass at 22-25 % (Wolf, H. 1997). Alternatives to lead in the glass panel are being examined, these include the use of barium, strontium and/or zirconium oxides.

The other source of lead is in soldering of electronic components in printed circuit boards. Standard eutectic solder contains 63 % lead and 37% tin. Alternatives, such as silver epoxy are proposed but require different processing technology and lower operating temperatures. Another alternative is tin/silver solder (96.5/3.5 Sn/Ag) where there is functional equivalence, although the silver solder requires a higher melting temperature (221° C verses 183°C). Another issue is the difference in cost Ag/Sn (ingot) $8.04/lb versus Pb/Sn $3.75/lb (Costic, M. et al 1996).

52% of the cadmium in MSW, was attributed to nickel-cadmium batteries. The remainder was made up of plastics at 28% and consumer electronics at 9 percent. This report was acted upon by the electronic and plastic industry where cadmium was used for electroplating and as a pigment (Delco Electronics Engineering Specification Q1000 Method 118). Cadmium has since been removed from all but non-essential operations.

This leaves nickel cadmium batteries as the main source of cadmium in MSW. Sales of mobile phones in Europe alone are estimated at 15 million, this is an increasing waste as Nickel Cadmium batteries are the main power supply. The change to Lithium/Ion may reduce this impact in the future (Ends Report 261 1996).

4.4.2 Mercury bearing components

Relays and switches are the major mercury-bearing components used in electronic appliances. In recent years manufacturers have made efforts to reduce the use of these components. However, mercury-bearing components are found in appliances entering the waste stream now and are still used in some new appliances.

4.5 Legislation effecting electronic waste

Various countries have proposed legislation to reduce the quantities of waste entering the MSW stream. Due to the globalisation of the market for electronic products when one country adopts strict eco-legislation manufacturers must comply or abandon the market.

Contrary to this, within the European Union, in the interest of fair trade no single country can adapt legislation that is a barrier to trade. However, on ecological grounds a country can enforce landfill restrictions for the disposal of waste.

4.5.1 Japanese regulations.

In 1991, the Japanese government passed the Law for the Promotion of Using Recycled Resources commonly known as the "Recycling Law." This law stipulates that air conditioners, television sets, refrigerators and washing machines must be designed with a view to easy recyclability. The legislation regulates both materials and methods of construction. In the October 1991 revision of the Law for the Treatment and Disposal of Waste Products (1970) stipulates that "businesses are responsible for the proper treatment of waste products generated in their business activities."

In 1995, large screen televisions and large volume refrigerators were designated as waste products which must be collected and disposed of jointly by their manufacturers and distributors. The manufacturers and distributors then created a co-operative organisation for the proper disposal of their products, which supported local governments' disposal activities. Japan requires the local authorities and the members of the electrical association to bear some of the cost of recycling. In Japan, just under 60% of all end-of-use electrical household appliances are recycled. Ferrous metals account for the bulk of the materials that are reclaimed, however, the use of plastics is increasing which is more difficult to recycle (Suzuki, Y. 1996).

4.5.2 European take back and recycling initiatives

In 1989 the European Commission recognised the stream of waste from electrical and electronic equipment as one of priority importance. In 1994, it set up a project group to develop proposals for EU action on the subject. This project group submitted a recommendation document in July 1995. However, the document failed in its purpose of providing concrete proposals for Community Action (Welker, A.M. 1996). The Commission Directorate General XI has since discontinued the priority waste stream initiative due to difficulties of management and of agreement by all interested parties (Warmer Bulletin 1996).

In the meantime, several EU Member States have been developing legislation that would require manufacturers and importers of electrical and electronic equipment to take back and recycle end-of-life electrical and electronic products.

Who will pay the costs of recycling is a key concern in most of the proposals. In the majority of cases these fees are to be borne by the consumer or the customer (Austria, France, Germany, Netherlands and Switzerland.) The manufacturers role varies from that of an advisor for information on recycling and product design as in France, to that of a co-owner in the recycling centres who share financial responsibility, as in the case in Japan. The reticence in enacting these legislation comes from the concerns that high costs tacked on to the purchase price may move consumers to other countries or states, where there is easy assess to other markets, resulting in a loss of sales in border areas (Pitts, G. 1996)

4.5.2.1 German Take Back Ordinance.

The German Federal Ministry of the Environment, Nature Conservation and Reactor Safety were the first to propose take back in their "Ordinance on the Avoidance, Reduction and Salvage of Waste from Used Electrical and Electronic Equipment (Electronic Waste Ordinance)" in 1992. The 1992 draft stipulated that the product chain (retailers, distributors and manufacturers) must collect and recycle used equipment by the establishment of a reverse distribution system that is free of charge to product users (Dillon, P. 1994). The latest draft "Draft Ordinance on the disposal of Information Technology (IT) Equipment", dated 20 February 1996 separates electrical and electronic products into three categories, grey (Information Technology), brown (stereos etc.) and white (domestic) appliances. It places on manufacturers and distributors the responsibility for collecting, recycling and disposing of used information technology equipment (Welker, A.M. et al, 1996). The key point of discussion is that manufacturers bear the responsibility for the cost of recycling or disposal. Appendix IX is a synopsis of the points under discussion in Germany at present. CYCLE is the IT industry's proposal and it was opposed by municipalities who want the industry to be cost responsible for the sorting/ recycling facility. (Schneider. A, 1997) Another point of note is that the ordinance does not specify that any recycling must take place, disposal is also an option. Also, the ordinance leaves manufacturers free to commission third parties to fulfil their duties under the ordinance (Welker, A. M. 1996).

4.5.2.2 Dutch Take-back Ordinance

The Ministry of Public Housing, Regional Planning and the Environment released a draft ordinance dated 5 July 1996, based on the Dutch Environmental Protection Act. The proposed ordinance would require suppliers of electrical and electronic products to take back, free of charge, a used product at the time of purchase of a similar product (new for old). These obligations would apply to most standard, mass produced household and office equipment. The ordinance does not determine how the taking back of the goods would be financed. Nor, does it stipulate how the equipment which has been taken back is to be re-used, it does prohibit burning the equipment.

4.5.3 U.S. pilot programs for electronic waste.

The US does not have any proposed legislation at present on recycling electronic waste but some municipalities have started pilot programmes to determine the most practical means forward.

4.5.3.1 The Minnesota Office of Environmental Assistance

The Minnesota Office of Environmental assistance published a report in 1995 on the Management of Waste Electronic Appliances. In this report the research findings were presented which identified lead, cadmium, arsenic and mercury as among those materials that pose environmental and public health concerns when they were managed as MSW. It also concluded that sufficient reclamation capacity existed for improved management of some electronic components, specifically CRTs and printed circuit boards. The report concludes with a recommendation that the state should prohibit disposal of certain electronic appliances in MSW. It proposed that the restriction be passed on business from January 1,1997 and from household from January 1, 1998.

4.5.3.2 New Jersey

The New Jersey Department of Environmental Protection (NJDEP) has proposed a de-manufacturing system with the goals of reducing heavy metals (cadmium, lead and mercury) in the MSW. The initial list of products include; mercury containing lamps, mercury switches, batteries, consumer electronic and appliances. It is estimated that source separation programs for these few categories of products can reduce the cadmium, lead and mercury content of MSW by over 90%.

4.6 Stages in Material Recycling.

4.6.1 Re-manufacturing.

Re-manufacturing or refurbishment of computers means repairing, replacing worn parts, upgrading the system with new integrated circuits (microprocessors) and selling again as a complete system. It is most suitable for newer computers that have been discarded due to obsolescence or minor damage. This is the most lucrative end of the recycling business as little disassembly is required and unusable products are very small. Multis in Galway is a company started in 1996 who re-manufacture computer equipment for the second-user market. 90% of the equipment comes from Digital who are also one of their customers.

Re-manufacturing does have the problem of implications of lower quality and the barriers of 'second-hand' status must be overcome. Computer consumers normally desire the latest technology making performance an overriding criteria. There is also the issue of marketing when integrating used components into supposedly new products. This may necessitate new labelling requirements (Frankel, C. 1996). Once a product has been recovered, refurbished and certified it must be brokered. Some markets exists by downgrading to less demanding applications; schools, third world countries and some industrial and commercial applications.

4.6.2 Recovery of Components

Disassembly of the larger parts of the system takes place here. Printed circuit boards and components are removed for reuse. Depending on the age of the system these components can be reused in toys, vending machines or control equipment. They may also be used as spares for service industries. A constant volume is needed to broker these parts effectively. Most effective recyclers are single source, such as Siemens Nixdorf Informationssteme (SNI) group. In 1988, SNI set up the Remarketing and Recycling Centre in Paderborn, Germany to take back and recycle decommissioned computers from its German dealers. When recovering components from their own systems they have a complete understanding of the products and a ready market to use them in the repair and maintenance of their systems through their dealer network (Kennedy, B. 1996).

For other third party recyclers who take systems from many sources the market value must be balanced against the cost of recovery in determining which devices will be recovered from what equipment (Biddle, M. et al 1994). If obsolete parts cannot be brokered they are recycled for their precious metal content. These recyclers require an extensive knowledge of an ever-changing market to determine the cost balance of components.

Both re-manufacture and recovery of components must be done in volume to be cost effective and to maintain a consistent presence in the marketplace.

4.6.3 Disassembly of products

During recycling of materials the products are disassembled, which is normally done manually using simple tools into their component parts or materials. As manual labour is expensive this stage adds high costs to the process. There are some mechanical processes, using shredding and separation techniques. These are less expensive to operate than manual but is its more difficult to obtain pure and more valuable fractions. MBA Polymers have commercialised a semi-automated process to separate different plastics and materials from scrap electronics. The feed of electronics is sifted using techniques based on different physical, electrical and magnetic properties (Dillon, P. 1994).

Many electronic companies are now looking at the whole aspect of disassembly. Philips Corp. examined disassembly modelling of a 21" Television set. The actual times taken were from their recycling facility. Approximately 4.5 minutes was required to break down the television into its component parts (Boks, C. et al. 1996).

Other institutions are busy examining theoretical energy and time calculations for snap fasteners versus screw fittings, which hold housings together, to determine which is the best option from a disassembly point of view (Lou, S. 1996). Recyclers suggest that this is wasted effort, as they have learned from experience how best to disassemble products. They suggest that it's actually harder to pry apart clips than to remove screws with an air powered tool (Biddle, M. et al 1994).

4.6.4 Recycling of materials

Once the products have been broken down into their component parts they are then ready for ultimate recycling. Taking these components or materials and reusing them in the manufacturing system.

4.6.4.1 Ferrous, non-ferrous and precious metals

Ferrous, non-ferrous and precious metals constitute the largest percentage by weight in computer systems. Metal recycling is well established and recovering metal from electronic products is built upon the existing scrap metal industry. In older printed circuit boards the precious metal content of 400-1400 grams per tons of gold made good economics for recycling. Newer equipment, however has only 150-450 grams per ton due to the use of copper instead of gold in electrical contacts (Biddle, M. et al 1994).

Printed circuit boards are recycled by specialist companies after all reusable and harmful materials have been removed. There are two main companies using pyrometalurgical techniques to recover the metals and process slags to inert epoxy compounds. The companies are Boliden and Norddeutsche Affinerie (Kyck, K. 1997).

The key to optimising metal recycling is to determine how much processing is warranted to remove components, plastic, glass or paper from the metal stream prior to transferring it to a refiner or smelter. A series of technologies are in limited commercial use for removing ferrous metals (using a magnet), separating copper and nickel (using an air classifier), and separating aluminium (through an eddy current separator). Another common application is where aluminium may have pieces of steel attached to it as screws, inserts or brackets. The mixture can be processed in a furnace, where the steel is left behind and the aluminium will go to a secondary melting operation. The material can be used for an aluminium based product, depending on its alloying requirements (Pitts, G. et al 1996).

4.6.4.2 Glass

Glass, in electronic waste, is mostly in the form of cathode ray tubes. They are a significantly difficult product to recycle effectively and very few companies do a full integrated recycling. Some recycling operations recover the glass by dismantling. In others, it is disposed of as a whole assembly either incinerated, landfilled or used as a fuel and material additive in cement kiln processes (Biddle, M. et al 1994). Due to the lead content of CRT's it is unlikely that these disposal options will continue in the future.

One recycling operation which does carry out complete recycling of CRTs is Hetzel & CO. Electronik - Recycling GmbH (HER) in Nurnberg, Germany. Appendix XI shows the breakdown of a television set. The CRTs (TV tubes) are prepared in a HER patented thermal process to remove the lead which is sent to a lead smelter for recovery. The glass goes through a further washing process to remove the luminescent powder which coats the front glass. This is a hazardous waste and therefore must go to a toxic waste dump. The two different types of glass are separated and sent for recovery. Herzel employ 70 people and recycle 2,500 CRTs from televisions and computer monitor per week (Wolf, H. 1997). The costs are part funded by the domestic refuse charge. Consumers can deliver the items personally or there is a kerbside pickup of larger items. Commercial organisations with large quantities are collected by Herzel's transportation services and are charged a fee for recycling.

4.6.4.3 Plastics

Plastic content of electronics poses the biggest problem for effective recycling. Resin identification technology is immature, at present, making plastic separation difficult and sometimes impossible for many plastic parts in electronic products. It is estimated that less than 2 % of the more than 2 billion tons of plastics used each year to manufacture computer and electronic equipment is recovered at the end of the product's useful life (Pitts, G. et al 1996). The difficulties of recycling plastics from computer systems includes:

1. There are over 12 families of plastics and hundreds of grades required to make up the plastics in electronic systems. This broad variety of materials increases the complexity of separation.
2. Lack of identification of the types of plastics used.
3. Large variety of different reinforcements, fillers and pigments. Changing the fillers can vary the material density and alter the properties, even within the same type of plastic.
4. Metal contamination such as wiring, brackets, structural pieces and moulded inserts.
5. Paints and metallic coating make identification, sorting and melt reprocessing much more difficult.
6. Labels attached to the plastic must be removed prior to sorting.
7. Existing plastics in the waste stream may contain flame retardant and other additives which are now being phased out. In which case the plastic must be landfilled and cannot be used again.

4.7 Improvement in Material recycling.

Key improvements are being considered in the design for the environment by computer industries. Considering that products entering the waste stream were not designed with recycling in mind. The next generation of products must improve the use of the earth's resources.

4.7.1 Software tools for disassembly.

At some point in the disposition process a decision must be made on whether to disassemble further or to dispose of the product. This decision must balance environmental issues with economic viability. The optimal disassembly sequence is the description of the best way to disassemble a product to maximise the profit gained by material recovery. ReStar is a recovery analysis tool developed by the Green Design Initiative at Carnegie Mellon University. It uses artificial intelligence to determine the economics of recycling (Navin-Chandra, D. 1993). The tool can be used it detect break-even points. For example, at a given point in disassembly whether it will take more energy to recover the materials than to make them from new sources. Points of maximum profit can also be measured in terms of any parameter such as emissions, energy, cost or disposal volume. The system can search hundreds of alternatives. At each point in the disassembly process the following issues are considered for each subassembly:

- Dismantle further?
- Send to Shredder?
- Sell?
- Remanufacture?
- Hazardous material in subassembly?

ReStar can be used as a design for the environment tool to assess design changes of a product regarding the disassembly stage. It is gaining acceptance in the electronic industry with some major customers such as IBM, Motorola and United Technologies (Hedberg, S. 1996).

4.7.2 Identification

It must be clear what types of components make up a given system, what hazardous materials, what recyclable or precious metals are present. ISO have developed a labelling standard ISO11469 which sets forth a protocol for the physical marking of different types of plastics. If used by the computer industry this would significantly improve future plastic recycling options and value.

A more comprehensive approach is been taken by CARE Vision 2000 (Comprehensive Approach for the Recycling of Electronics) Their mission is to create an optimised set of solutions for product take back. CARE are developing a standard communications protocol for providing recycling and reuse information. This is termed the 'Green Port' which would be installed within the product .Information on recycling data and re-use data would all be available to the recycler including disassembly instructions. See Figure 4.4 on the green port.

Another possibility for plastics is a recent patent by the University of Southampton to inject an electric charge into the plastic during processing This would mean an automatic system for sorting of plastics could be envisaged (Frankel, C. 1996).

Recycling data			Reuse data	
Manufacturer	Recyclability	Additional Functions	Lifetime Data	Extension
Name Date of Production	Materials' names Additives Purity Precious metals Locations	Serviceability Data in power management Protection against claims for guaranty	Maximum Voltage Maximum temperature Maximum Impact Operation Hours	For future needs
A	B	C	D	E

Fig 4.4 The Green Port

4.7.3 Design for the environment

Designers have improved products by the use of fewer materials and the use of plastic materials with a recyclate content. The types of plastics used in computer products have been consolidated into a few families, namely; polyvinyl chloride, ABS and polycarbonate/ABS blend. This approach will improve recycling in the future and is easing the procurement of plastic materials (Ching, S. 1996).

An example of this is Siemens Nixdorf; A computer manufactured by them in 1987 weighed 16 kg, had 87 different parts, was assembled in 33 minutes and disassembled in 18 minutes. A computer manufactured in 1996 weighed only 6 kg, contained 14 parts, took eight minutes to assemble and only five minutes to disassemble (Kennedy, B. 1996).

4.7.4 Use of recycled plastics

The use of plastic materials with a recycled content is critical to effective recycling of plastics. Ideally, plastics should be closed loop or reused in the computer industry as the properties that they possess are retained. At present this is not feasible as the small amount of computer scrap available falls into this category. Currently, original equipment manufacturers must rely on other sources of recycled plastic to satisfy supply requirements. These open loop recycled materials are been made available for use in limited supply. Many times their recoveries are more expensive because of the computer industry specifications for flame retardancy, colour and quality. An example of open loop recycled material is General Electric's 'Cycoloy REY295 PC/ABS material which reportedly contains a minimum of 25% pre-consumer recyclate recovered from metallized compact disks. In the UK, IBM has closed-loop recycled over 500,000 pounds of PVC from keyboards. This involves the collection of parts by IBM, UK, disassembly, sorting and processing into flakes by the Mann organisation. The compounding is by a joint effort through Geon and Norsk Hydro. IBM gained a 22% cost saving over the price of virgin PVC. The lack of feedstock means that the expansion of its use is restricted.

4.8 Conclusion.

The recycling of electronic goods is at a very immature state at present. It must be stated that no recycling takes place until a part or material has been reused. Building stock piles of mixed plastics that have no commercial use does not constitute recycling. The review of the EU waste strategy is now questioning the value of incineration for energy which is the main recycling option for mixed plastics (Rose, M. 1996).

The cost of recovery may not outweigh the value of the recovered material. The question of who will pay the costs is uppermost in all discussions of draft take back regulations in Europe. If, as is proposed, manufacturers are to pay the cost of recycling and disposal, these costs will be re-directed back to the consumer by increased prices.

Waste management strategies are based on prevention of waste as the first priority, followed by recovery of waste and finally its safe disposal (ISO 14000) The innovations by computer manufacturers such as Apple, IBM and SNI to reduce the environmental impacts by producing smaller, less hazardous systems does reduce the quantity of waste but does not reduce the built in obsolescence in the design of these systems. The useful life is determined by the software packages that the system will support, forcing consumers to discard a system which cannot support a new business requirement. This is on the second tier of waste management

The take back initiatives from Europe are aimed at reducing the amount of this waste stream that enters the landfill stage for reasons of lack of space, cost, hazardous components and loss of resources. The logistics of operating the system of take back are not defined. In the literature there are both large manufacturers operating their own recycling facilities and integrated recyclers who take many types of electronic goods from various manufacturers. Both operations ultimately have waste residues.

This is perhaps an unduly negative view, and discounts the many benefits that are already being achieved.

Pressure has been placed on designers to think more carefully about components, and their potential to pollute, and also to avoid a multiplicity of components made from different materials.

Chapter 5 Case Study

5.0 Introduction

Harris Ireland is a semiconductor manufacturer. The main product is a varistor, which provides surge protection in electronic circuits. This product is made up of metal oxides, the main one being Zinc Oxide. The range of varistors produced vary is size from 3mm diameter and 1 grams weight to 60mm diameter and 650 grams in weight. These products are generically called monolayer, as the active area is sandwiched between two electrodes. The manufacturing stages are as follows:

1. Powder manufacture: The metal oxide additives are dispersed in water with some binding ingredients to form a homogenous mixture. This mixture is then spray dried to form a powder.
2. Disc manufacture: The powder is pressed into disc form and sintered at high temperatures (1200° C). The sintered device is then electroded on both surfaces of the disc with silver paste.
3. Assembly: Using high speed assembly equipment solder plated copper leads are attached by tin/lead solder. The device is then encapsulated for protection, after which it is electrically tested and packaged.

A new product was developed as a response to increasing market pressure for size reduction. This product is called a multilayer varistor as the active area is again between the electrodes but there are between 4 and 18 electrodes inside the component. The device is 3 mm x 1.5 mm in size and weighs 0.25 grams. The manufacturing stages of a multilayer device are as follows:

1. Powder manufacture: As above
2. Paste manufacture: The powder is ground and made into a paste by the addition of a natural solvent so that it can be screen printed.
3. Fabrication: The paste is then screen printed in combination with electrode material to build up the layers of the varistor.
4. Sintering: The devices are then sintered, as above, and electrical contact is made with the outside of the device by placing an end termination on each end.
5. Test and Packaging: Devices are electrically tested and packaged into single pocket PVC reels.

Appendix XI show the internal construction of a multilayer.

5.1 Selection of Analysis Tool

To determine the environmental impacts of the change from one device type to another it was proposed to use one of the environemntal analysis tools as outlined in the Chapter on Design for the Environment.

The Northern Telecom Environmental Index was deemed inappropriate for the analysis from one change in product type as it is a yearly database of all aspects on a company's environmental performance.

Life Cycle Cost analysis was considered very carefully as much of the information required for the internal costs of manufacture was available through the system of ABC accounting. However, information on the other life cycles was not easily computed.

The Canadian Standards Association Matrix and Life Cycle Assessment were ruled out as being too complicated, too expensive and not feasible due to lack of available data.

It was decided to use a combination of the "Environmentally Responsible Product Assessment Matrix" as proposed by AT&T and design requirement improvement tool.

The Environmentally Responsible Product Assessment Matrix was selected because of the ease of use and any information that was unavailable could be rated by comparing one device type against another.

The design requirements were specified from customer requests for information, they included the following:

- No Ozone depleting compounds in product manufacture;
- No Polybrominated biphenyl flame retardants;
- No Class 1 carcinogens;
- Product to be classified as non hazardous waste at final disposition.

5.2 Evaluation of environmental concerns

The functional unit was decided as a V18 x7 mm monolayer device compared with a V18 x1210 multilayer. These products would have equivalent function in most instances.

The system boundary was decided as starting from the powder manufacturing stage. To determine the impacts of the raw material acquisition would require a great deal of data that is not available. Therefore, the powder manufacture was defined as the 'pre-manufacture' life cycle stage as regardless of the environmental impacts form the raw material acquisition, it is equivalent for both devices.

The functional unit was defined as one device.

The device was only considered under the normal operating conditions, no valuation was given for abnormal conditions in the manufacture or use of the device.

Environmental Concerns

Life cycle stage	Materials Choice	Energy use	Solid residues	Liquid Residues	Gaseous residues	Total per life cycle
Pre-manufacture	(1,1) **1**	(1,2) **2**	(1,3) **2**	(1,4) **3**	(1,5) **4**	**12**
Product manufacture	(2,1) **2**	(2,2) **1**	(2,3) **2**	(2,4) **4**	(2,5) **3**	**12**
Product packaging and transport	(3,1) **4**	(3,2) **3**	(3,3) **3**	(3,4) **4**	(3,5) **3**	**17**
Product use	(4,1) **4**	(4,2) **4**	(4,3) **4**	(4,4) **4**	(4,5) **4**	**20**
Product disposition	(5,1) **2**	(5,2) **2**	(5,3) **2**	(5,4) **4**	(5,5) **4**	**14**

Figure 5.1 Matrix for Monolayer device

Score: Environmentally Responsible Product Rating (R_{ERP}) 75 %

Environmental Concerns

Life cycle stage	Materials Choice	Energy use	Solid residues	Liquid Residues	Gaseous residues	Total per life cycle
Pre-manufacture	(1,1) **3**	(1,2) **3**	(1,3) **3**	(1,4) **4**	(1,5) **4**	**17**
Product manufacture	(2,1) **3**	(2,2) **3**	(2,3) **4**	(2,4) **3**	(2,5) **3**	**16**
Product packaging and transport	(3,1) **2**	(3,2) **2**	(3,3) **2**	(3,4) **4**	(3,5) **3**	**13**
Product use	(4,1) **4**	(4,2) **4**	(4,3) **4**	(4,4) **4**	(4,5) **4**	**20**
Product Disposition	(5,1) **3**	(5,2) **3**	(5,3) **4**	(5,4) **4**	(5,5) **4**	**18**

Figure 5.2 Matrix for Multilayer

Score: Environmentally Responsible Product Rating (R_{ERP}) 84%

5.3 Results

Comparing the two devices the matrices were build up on the following points:

The terminology used here is, as in the table, for example,

(1,1) refers to material choice in the pre-manufacture stage.

[2,2] refers to the value given in the study. The first value is for the monolayer device and the second value is for the multilayer device.

The values for the matrix were determined as follows:

5.2.1 Pre-manufacture

<u>(1,1) **[1,3]**</u>

Reduction in the amount of material required by a factor of 7.

<u>(1,2) **[2,3]**</u>

Further energy use is required in the extra processing stages of the multilayer device but there is significant energy reduction per device.

<u>(1,3) **[2,3]**</u>

Solid residues are of the same nature but seven times less.

<u>(1,4) **[3,4]**</u>

Liquid wastes are reduced, for reasons as above.

<u>(1,5) **[4,4]**</u>

Gaseous residues low and of negligible impact.

5.3.2 Product manufacture

<u>(2,1) **[2,3]**</u>

For the multilayer device, selection of a naturally occurring vehicle in the printing operation reduces the impacts of material choice. There is elimination of a hazardous component in the encapsulating stage of the monolayer device.

(2,2) **[1,3]**

Significant reduction in energy requirements in the sintering stage of manufacture.

(2,3) **[2,4]**

Reduction in processing stages eliminates solid residues.

(2,4) **[4,3]**

Addition of liquid residues to process but these residues are recyclable.

(2,5) **[3,3]**

Gaseous residues, although not a major concern, have increases in the multilayer device with the screen printing stage. This is offset by the reduction overall in the sintering stage.

5.3.3 Product packaging and transport

(3,1) **[4,2]**

Change from cardboard packaging in bulk form to individual packaging in PVC pockets on a reel.

(3,2) **[3,2]**

Increase in energy used in the manufacture of PVC.

(3,3) **[3,2]**

Increase in solid residues from packaging.

(3,4) **[4,4]**

The liquid residue effects were deemed to be negligible.

(3,5) **[3,3]**

The gaseous residue effects would be from the transportation and distribution stage are assumed to be equal

5.3.4 Product use

Section 4 Environmental concerns in all aspects of the product use stage were insignificant due to the fact that the device is a passive component, does not use any energy, does not degrade over time and is not used up in the process.

5.3.5 Product disposition

(5,1) **[2,3]**

Reduction in the quantity and variety of the materials used and elimination of a hazardous component leads to easier disposal or recycling methods.

(5,2) **[2,3]**

Devices are recyclable for their metal content. However, this does require smelting which does have an energy requirement.

(5,3) **[2,4]**

In the case of disposal to landfill there is a significant reduction in quantity and the reduction of a hazardous component.

(5,4) **[4,4]**

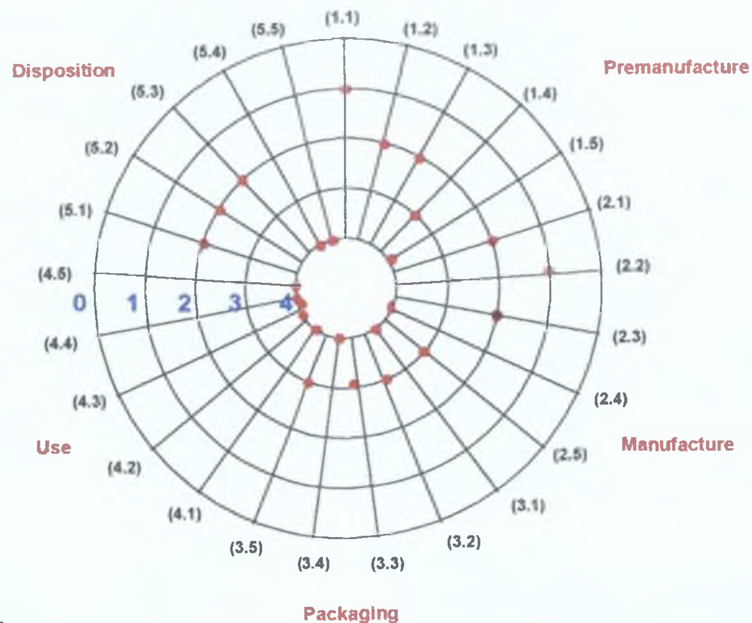
The liquid residues could not be easily computed but due to the inert nature of the devices they were deemed insignificant.

(5,5) **[4,4]**

The gaseous residues could not be easily computed but due to the inert nature of the devices they were deemed insignificant.

The results were plotted on target plots to demonstrate the overall environmental effects of the products

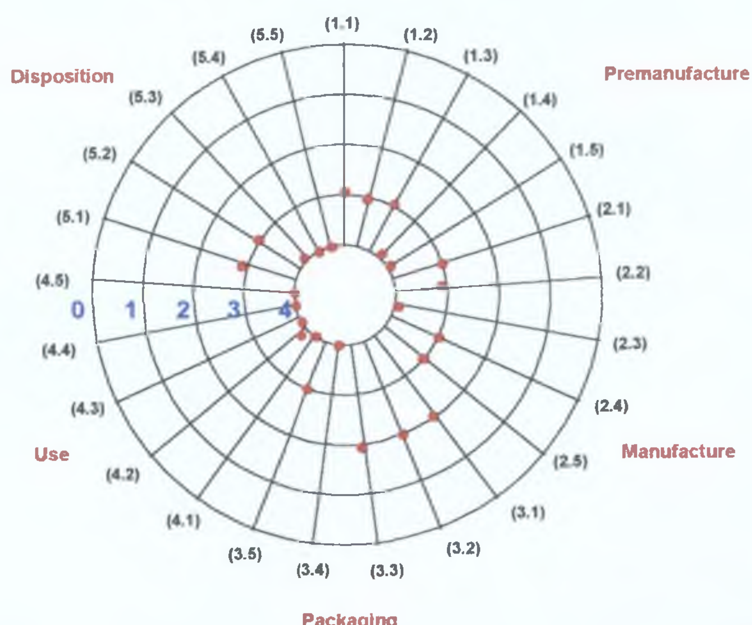
Figure 5.3 is a target plot of the monolayer device and Figure 5.4 is a target plot of the multilayer device. The plots were constructed by plotting the value of each element in the matrix at a specific angle. (For this 25 element matrix, the angle spacing is 360/25 = 14.4°). Both products are good in that the plots are closely bunched in the centre. The bad elements are highlighted by being far removed from the target The environmental responsible product rating improved from 75% to 84% as a result of the change from monolayer to multilayer construction. The main area that made up this rating overall is the fact that device is passive by nature and as such has no impacts during the use stage.



Monolayer

Score $_{ERP}$ =75%

Figure 5.3 Target plot for monolayer



Multilayer

Score $_{ERP}$ =84%

Figure 5.4 Target plot for multilayer

5.4 Discussion

The matrix highlights easily the areas needing attention. In the case of the monolayer the most significant impacts are in the pre-manufacture stage. In this instance this is the powder formulation stage and the reduction in impacts is due mostly to the reduction in the size of the device. The pre-manufacture stage went from a total score of 12 to 17

Energy use in the manufacturing stage is an area needing attention as this is a significant concern. The reduction in energy combined with reduction in solid waste reduced this life cycle stage from 12 to 16.

The impact of the new packaging for the multilayer device has changed the aspect of this stage. This is the one life cycle stage that increased with the introduction of the multilayer. The packaging specification is determined by the customer as the devices are inserted into circuit boards by the use of high speed 'pick and place' machines. Improvements in this area would be difficult to make.

The product use phase carries no environmental concerns as the device is passive in nature.

The retirement stage of the cycle holds some impacts depending of the disposition of the product. Unknowns of actual disposition are estimated.

5.5 Conclusion

This analysis tool can be adapted quite easily providing there is in depth knowledge of the product and some expertise on environmental effects. This analysis is based on a comparative basis only. For example in material choice of the pre-manufacture stage and the energy use of the product manufacture stages all impact are reduced by a factor of seven due to the reduction in weight.

The area which was found most difficult to determine was the disposition stage, how the device is disposed off is unknown. The devices are recyclable for their metal content but this may not be a feasible option if other components on the circuit boards are not. The devices can be used in electronic products from a radio to a car and all disposition scenarios cannot be determined in one matrix. It may be more suitable to separate this area further into refurbishment, recycling or disposal so that all options can be examined.

The significance of the environmental concerns are based on a comparison bases only and are internal to the company. For example, the rating of 1 in the pre-manufacture stage for energy, emphasises its significance in the manufacture of varistors, if it was compared against another product such as an integrated circuit its rating could change.

The combination with the design requirements gave immediate focus to the project as customer requirements are a significant part of every manufacturing facility.

The visual target plots are a very good communication tool to demonstrate effects of products throughout their life cycle and to explain DFE to other management functions.

This analysis tool is ideal for internal use in a company when used to compare the impacts of its products and processes as they relate to the company's environmental goals and objectives.

Chapter 6 Conclusion

6.1 Introduction

The key motivation in addressing the environmental considerations of electronic products at present are driven from the disposal of an increasing waste stream. Taking a strategic perspective on environmental issues is shifting the focus from coping with waste to designing products which minimise that waste. Environmental issues may no longer be regarded as apart from social and economic policies. All business is based on economic conditions. The goal of sustainable development is to continue development but with a reduced dependency on the earth's resources. A summary of the important techniques examined in this thesis will be provided here with their most salient points. The chapter will conclude with the important issues required to develop the techniques further.

6.2 DFE techniques

DFE techniques in use at present reflect the difficulties of incorporating environmental considerations into an already complex system. No individual technique incorporates all the parameters necessary to design a product. The overriding factors in a product development are: potential market for the product; profit margin and time to market.

6.2.1 Analysis Techniques

The techniques examined cover the life cycle stages of a product for the environmental concerns. The stages of the product are in all cases: pre-manufacture; manufacture; distribution; use and disposal. Where the techniques differ is whether pre-manufacture goes outside the factory to the environmental impacts of producing or mining of the raw materials. The environmental concerns vary depending on the country that developed the techniques but consistently contain product inputs and outputs; releases to the environment and energy use.

The Canadian Standards Association matrix can assist the designer in which areas to look, but the amount of information required is onerous. The environmental concerns of hazardous material risk, global warming and local concerns will need to be sub-divided and separated over the life cycle stages.

6.2.2 Life Cycle Cost Analysis

Cost analysis is the most influential tool guiding decision making. The research completed by Philips to correlate environmental impacts with life cycle costs appears to possess potential. However, the cost analysis suggested here only includes the costs to the producer and to the consumer. Life cycle costs can be analysed from three perspectives: producers, consumers and society at large.

6.2.2.1 Producers Costs

From the producer's perspective environmental costs need to be allocated accurately to the areas of production which creates the cost. Normally, environmental costs within a factory are combined into overhead costs where they cannot be separated into costs of treatment, waste resources and disposal or measuring and monitoring costs. By changing the responsibility for these costs to the line manager or engineer who creates the waste or emissions there is then an impetus to focus on these costs. Activity based costing can be a way of properly assigning product costs to the areas of the production that cause the costs. These costs can then be computed to provide direct life cycle costs of the production stage.

Prices for goods and services, at present do not fully reflect the total costs or benefits. For this reason, a design that minimises environmental burden may appear less attractive than a less responsible environmental alternative.

6.2.2.2 Consumer Costs

Life cycle costing could be useful from the consumer's perspective to aid product selection decisions. In traditional use, life cycle costs consist of the initial purchase price plus operating costs for consumables, such as fuel or electricity, and servicing not covered under warranty as well as possible disposal costs or resale value. Providing estimates of life cycle cost can be a useful marketing strategy for environmentally sound products.

6.2.2.3 Costs to Society

The life cycle costs to society can be seen to be outside the original transaction between the producer and the consumer. These are the most intangible costs. They include: the depletion of natural assets, which is the using up of the earth's resources; costs of degradation of the environment, including air quality, pollution incidents, river quality and land; defensive expenditure which is the cost to remedy environmental damage, the cost of health care caused by environmental damage. These costs cannot be quantified unless a system is developed to monetise them. Despite various indicators linking the environment with economic performance it is difficult to place value on a human life or human well being.

6.2.3 Improvement Tools

Improvement tools suggested are most applicable for internal use and for comparison purposes. The "Environmentally Responsible Product Assessment Matrix" is useful from its ease of application and visual presentation that may be of assistance in simplifying the complex nature of environmental aspects to a level which can be comprehended by all members of product development teams. The area needing further development is that of final disposition. This is more a reflection of the waste management issues prevailing in the industry at present, than a fault in this design tool.

Design requirement techniques are becoming commonplace within the industry as the effects of the environment goes further back in the supply chain. The hazardous substances included in restricted lists reflects the reaction of original equipment manufacturers to the pressures bearing on them for improvements. Their use of these lists is restricted to the present knowledge base. As further scientific knowledge is gained on substance effect on the environment the lists will require updating but it is unlikely that any substances will be removed, only additions will be made.

The German Blue Angel for PCs is a good example of a design blueprint. Its strict criteria ensure that the logo is achievable and maintains the high standard that it expects. The importance will really become known if it is used as a blueprint for the proposed PC Eco-label.

6.2.4 Methods for improving the environmental performance of a product.

Product system life extension encompasses many of the other methods of improving performance such as re-manufacture, re-use and recycle. Ultimately to reduce dependence on materials and energy, change is required from single use of materials to many potential uses. Industrial ecology studies the link between human economic activity and fundamental natural systems.

Re-manufacturing requires both design and business logistics which can ensure a means of collection of old systems and available markets for re-manufactured systems. The process at present is mainly suitable for large, high value systems which are controlled by the manufacturer.

Industrial ecologists suggest that to progress towards sustainability requires a movement towards "functional economy" where customers are offered services, rather than products. This would mean that, a computer manufacturer would no longer sell only products but would lease state-of-the-art systems for a defined period, which would include all services and maintenance. At the end of this period the manufacturer would take the system back, replace it with another system and re-manufacture the original system.

The concept of product system life extension requires some difficult questions to be answered. If the useful life of products are extended then fewer products are sold and manufacturing profits decrease. Fewer factories and manpower are required, jobs are lost and the economy suffers. Looking at this scenario from Ireland's perspective, would Intel require 3000 people? If Hewlett Packards inkjet cartridges were re-useable would this company still employ 3000? Industries are in the business of making money and are welcomed by all governments because of the contribution they make to the economy and employment they create. Design for the environment is the ultimate method of sustainable development but if it has the potential to restrict economic growth it will not succeed.

Designing for disassembly and re-use is where the majority of research is focused at present.

6.3 Life Cycle Assessment

Life cycle assessment is the most comprehensive analysis tool for understanding the environmental aspects of a product. This comprehensive nature is also its difficulty. The issues of data quality and methodology are leading to a very uncertain future for LCA. Acrimonious disputes over the quality of LCAs published reduce the value as a decision support tool.

ISO 14040 has not helped the situation by producing a standard which is mainly a guideline which can be interpreted by different practitioners in different ways. The fact that there is a separate method for internal and external LCAs means that its use to decision makers may be strictly limited. Internal use for company decision making does have potential but external use for policy making will be unsuitable unless all methods and data are equal.

6.3.1 Life Cycle Inventory Analysis

Life cycle inventory analysis is most developed at present and some results have been published. The HP deskjet print cartridge is a good example, from the electronics industry, of a life cycle inventory analysis, which has been thoroughly completed by the researchers. Many of the other published LCAs are from the commodity producers such as steel, aluminium and packaging. These are different from the point of view that their motivation for carrying our the LCAs were for the purpose of influencing government policy rather than for life cycle improvement. Much of the information is proprietary and is held back from the published report. The agreement on a single method and data quality for these commodities is necessary for the process to develop further to more complicated products containing many commodities.

6.3.2 Life Cycle Impact Analysis

Impact assessment in the life cycle is where the environmental concerns are defined and characterised based on their impacts on certain categories. Analysis of significance and evaluation are the most difficult steps in impact assessment. To determine the relative importance of the effects requires that a system of ranking and target levels is globally applied and agreed. Determining the target levels for impact categories has not been developed yet.

The selection of target levels poses many problems. Even if a direct relationship has been established between and an environmental burden and its impact on the environment, such as the use of CFC's and the damage to the ozone layer, the nature of the relationship may change over time as other factors of the system evolve. Some of the change is not predicable from it's previously known characteristics. The base line for environmental concerns for the design for the environment techniques may change with time as more information becomes known. Monitoring of long term trends and measurement of the whole system is required to ensure that no adverse effects on other eco-systems or global impacts occur.

The Eco-indicator system is the most comprehensive available and has been developed over many years with the aid of the Dutch Department of Health. The software packages such as Simipro and Team do assist in the completion of LCAs but again are as good as the databases they contain. No research has been carried out to test if different software packages would give the same result for the same product.

6.4 Electronics goods recycling

The amount of electronic goods in the waste stream is rising and could become a significant problem. At present this amounts to 1 percent of municipal solid waste but because it is non-biodegradable and contains hazardous components governments are concentrating on it. The German take back ordinance is almost ready to be introduced and this will have repercussions for all manufacturers who wish to be present in Germany or other European markets.

The two types of recycling which takes place at present are: first party recycling by the manufacturers on their own products and third party recycling by integrated recycling facilities who take all makes of goods.

The task of collecting and disassembling a company's products (which sell all over the world) is, under current conditions, a massive undertaking for a company which is in the business of manufacturing and not dismantling.

An efficient collection system such as, that which has developed for glass recycling, is needed to encourage those engaged in manufacturing electronic goods to enter the recycling chain.

The removal of hazardous materials from these goods will assist in the potential recycling ability. Until there is a policy change within governments the recycling of materials will be based on economic ground; cost of collection, disassembly and recycling versus the cost of new materials.

6.5 EPA and ISO 14000

In Ireland, the EPA Act of 1992, allowed for the licensing of activities with the potential to cause damage to the environment. As part of the conditions of most licenses there is a requirement to continuously improve the environmental aspects of the process. ISO 14001, Environmental Management Standard, also specifies continual improvement of environmental effects. If this becomes an industrial standard as ISO 9000 has become for quality, it will have an incremental improvement form 'gate to gate' aspects. As each industry, from the miner of resources to the supplier who makes components, to the manufacturer who put all the parts together, becomes accredited by ISO 14000 or IPC licensed each stage of the manufacturing will separately improve without the complete coverage of all life cycle stages.

The manufacturer of the end product cannot know or be responsible for the impacts along the supply chain but can guide the practice by expecting EMS from all the suppliers.

6.6 Government Policy

Government policy at present encourages manufacturing by providing grants for job creation. If grants were applied to recycling or re-manufacturing this could have an impetus to manufacturers to consider design for the environment in its products. Similarly, if grants were available for the use of recycled materials, this would make them more economic to use than new materials. If there is an added cost to the use of recycled materials they will not be economic to use and it will not happen.

6.7 Information and education.

Governments agencies have a major responsibility in supporting research to develop and co-ordinate the environmental databases necessary for DFE and LCA. Lack of environmental data is currently a major limitation for decision makers on product development.

Education at third level could be one of the most effective techniques to promote sustainable development. Industrial programmes are far ahead of academic courses. It is necessary to educate the next generation of engineers that the environment means more than a sewerage treatment works or a wet scrubber system and move towards the education of pollution prevention, clean technologies and integrating environmental issues into design. Faculties do exist such as the green design initiative at Carnegie Mellon University, the University of Michigan and Windsor but design for the environment must become part of the syllabus of all third level institutes. IEEE also are a major source of information for the electronics industry and are leaders in this research.

6.8 Consumers

Consumer attitude must change towards products. In recent years consumers are less tolerant of inappropriate manufacturers who are seen to be environmental polluters (Brent Star) but there is an underlying belief that manufacturers alone are the polluters and they have no part to play.

There is a belief that technology will solve all problems but this is not the case. Technology can only improve in the direction demanded by the consumer.

6.9 Conclusion

Our present rates and patterns of resource consumption and the corresponding waste generation are unsustainable. Environmental design techniques can optimise material value while minimising resource consumption and waste disposal. Designers pay a major role in defining and solving design problems, but designers alone cannot reconcile economic, social and environmental policies.

Further research is required on improvement techniques for the electronic industries and methods of streamlined LCAs to make them more easily incorporated into the manufacturing facility. This author will be continuing research into the incorporation of environmental design techniques into the manufacture of discrete electronic components.

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APPENDIX I

AC Delco Regulatory Compliance

Restricted, Toxic, and Hazardous Materials Compliance

This letter is to certify that ________________________________ ensures that
(supplier name)
all materials and manufacturing processes used in part manufacture satisfy current governmental and safety constraints on restricted, toxic and hazardous materials; as well as environmental, electrical and electromagnetic considerations applicable to the country of manufacture and sale.

Name (signature): ______________________________

Name (print): ________________________________

Job Title: ____________________________________

DE assigned vendor code:________________________

Company Name: ______________________________

Address: _____________________________________

____

____

Phone Number: _______________________________

Date: ____

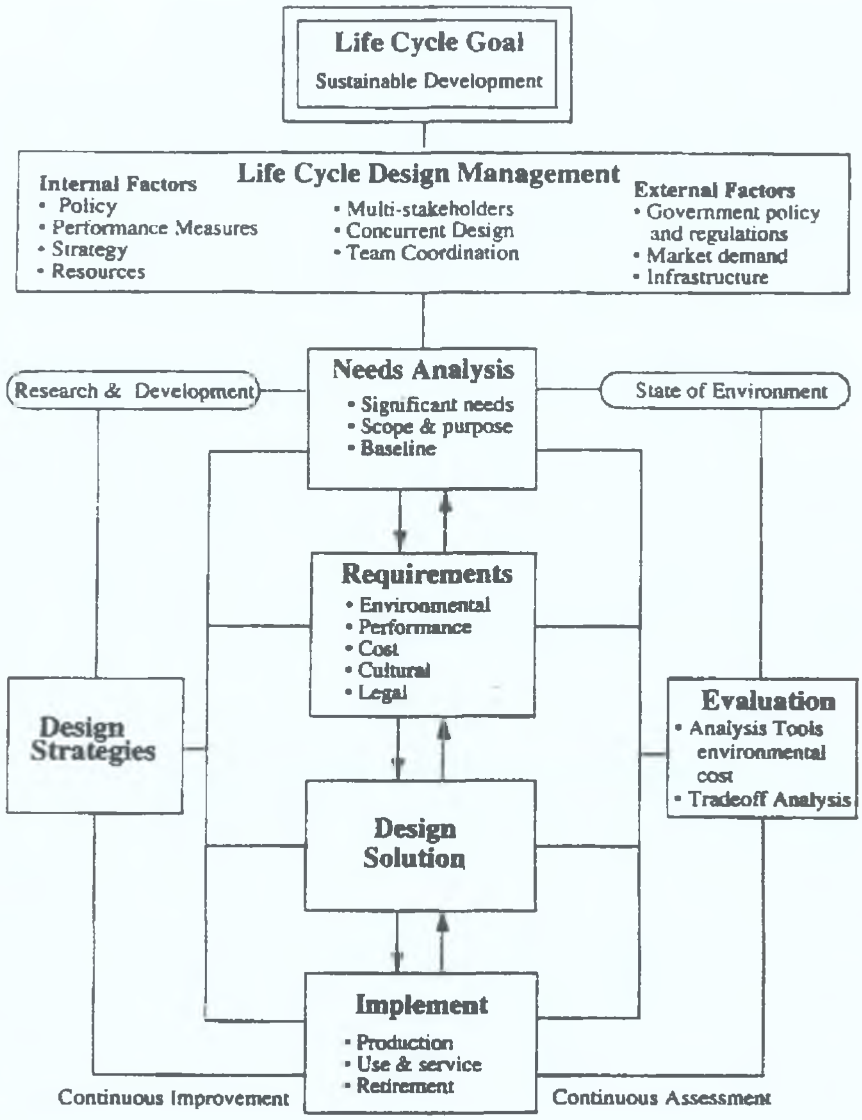
Return by March 1, 1997. Address this form and any questions to:

Lowell Gafford
Delco Electronics Corporation
2705 S. Goyer Rd.
M/S D6
Kokomo, IN 46904-9005

Phone number: 317-451-3903

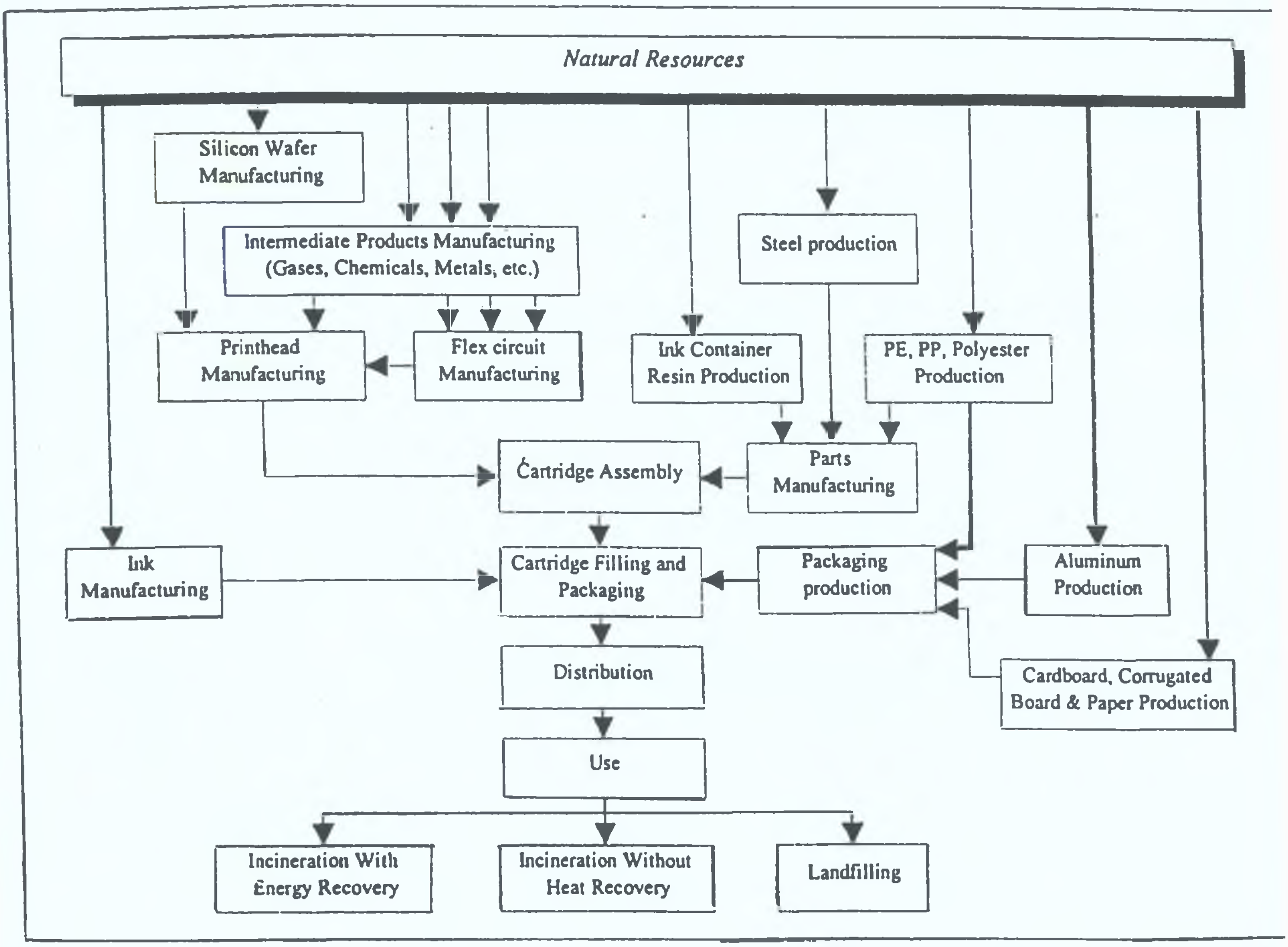
APPENDIX II

Life Cycle Goal



APPENDIX III

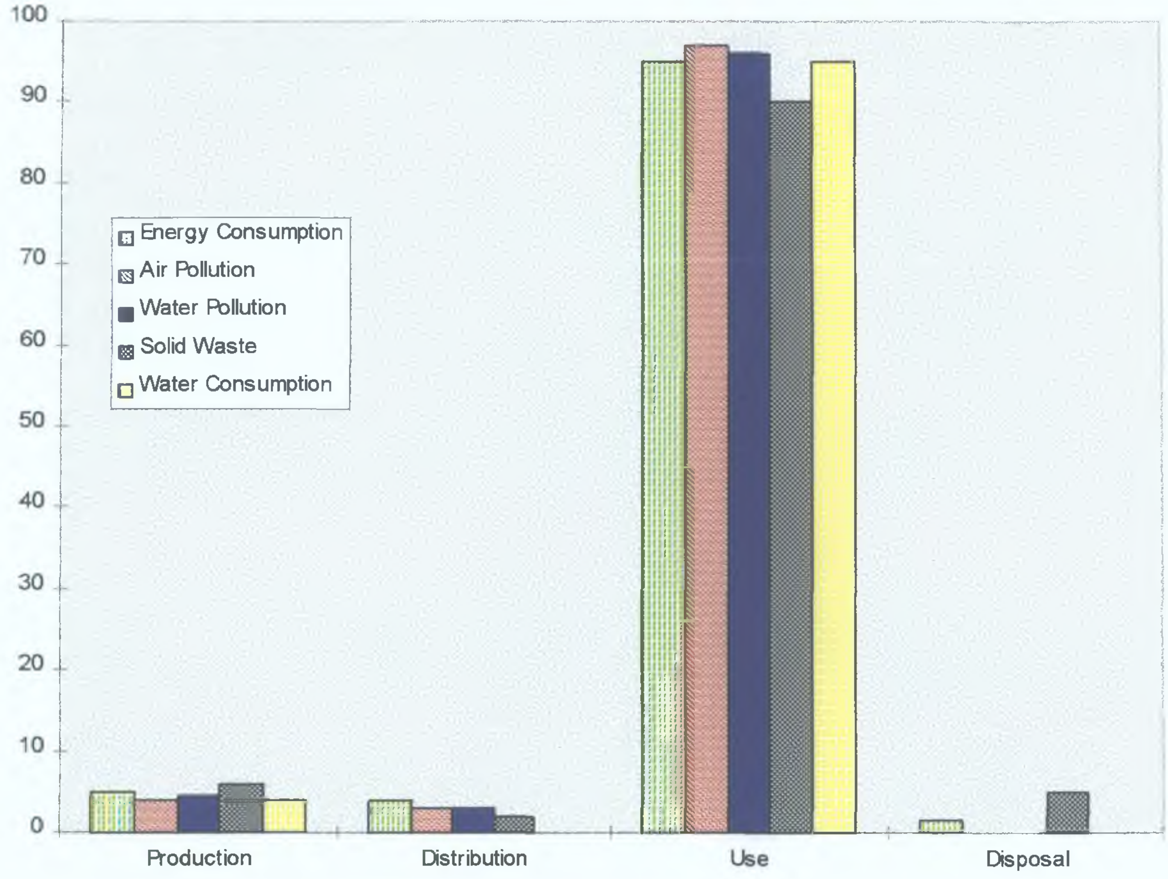
Inkjet Printer Cartridge boundary for LCA



APPENDIX IV

Life Cycle stages of a washing machine.

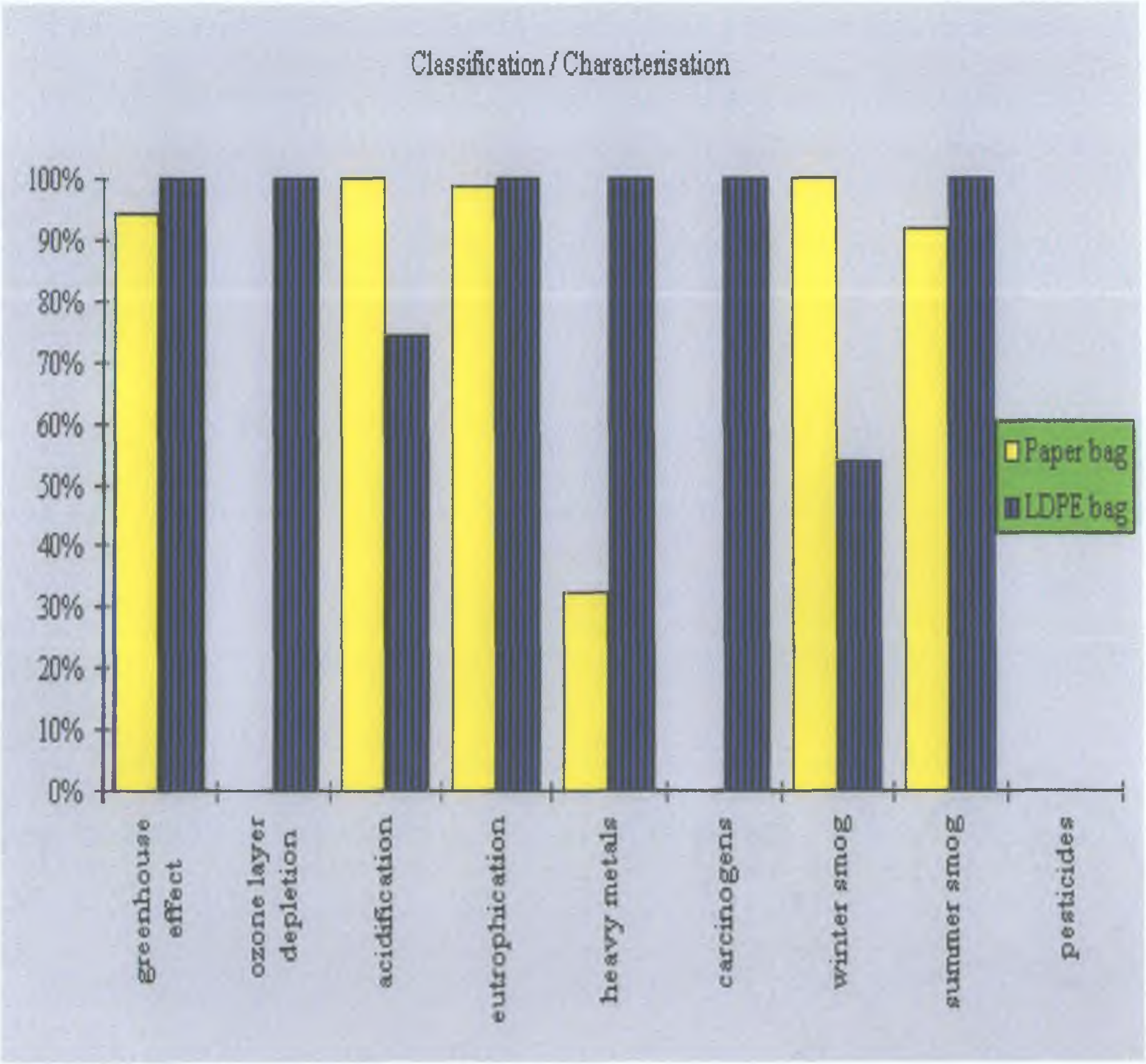
Life Cycle Inventory analysis of a washing machine.



Source: Eco-labelling on washing machines.

APPENDIX V

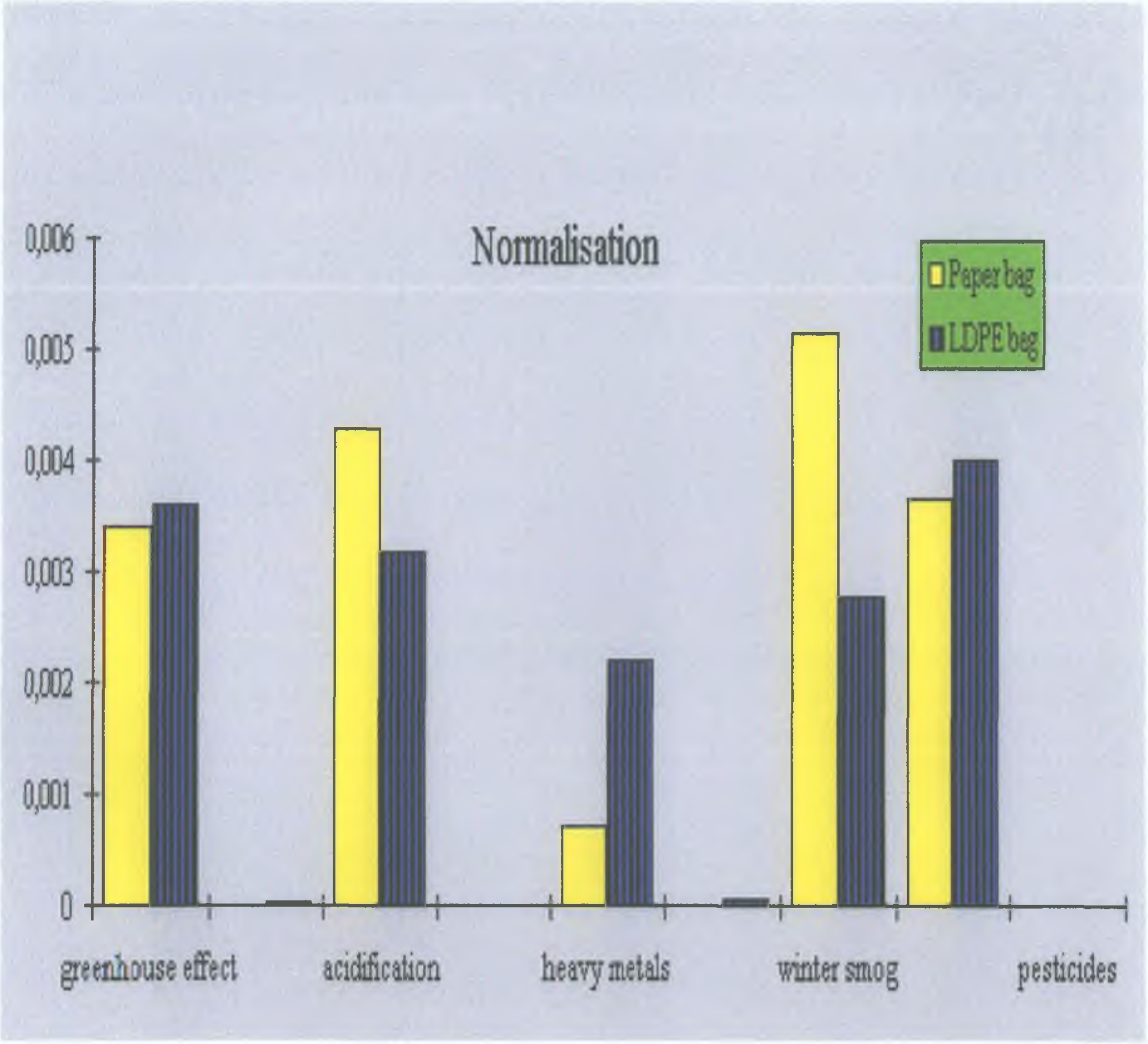
Classification/Characterisation stage in life cycle impact assessment.



Source: Simapro 3.1

APPENDIX VI

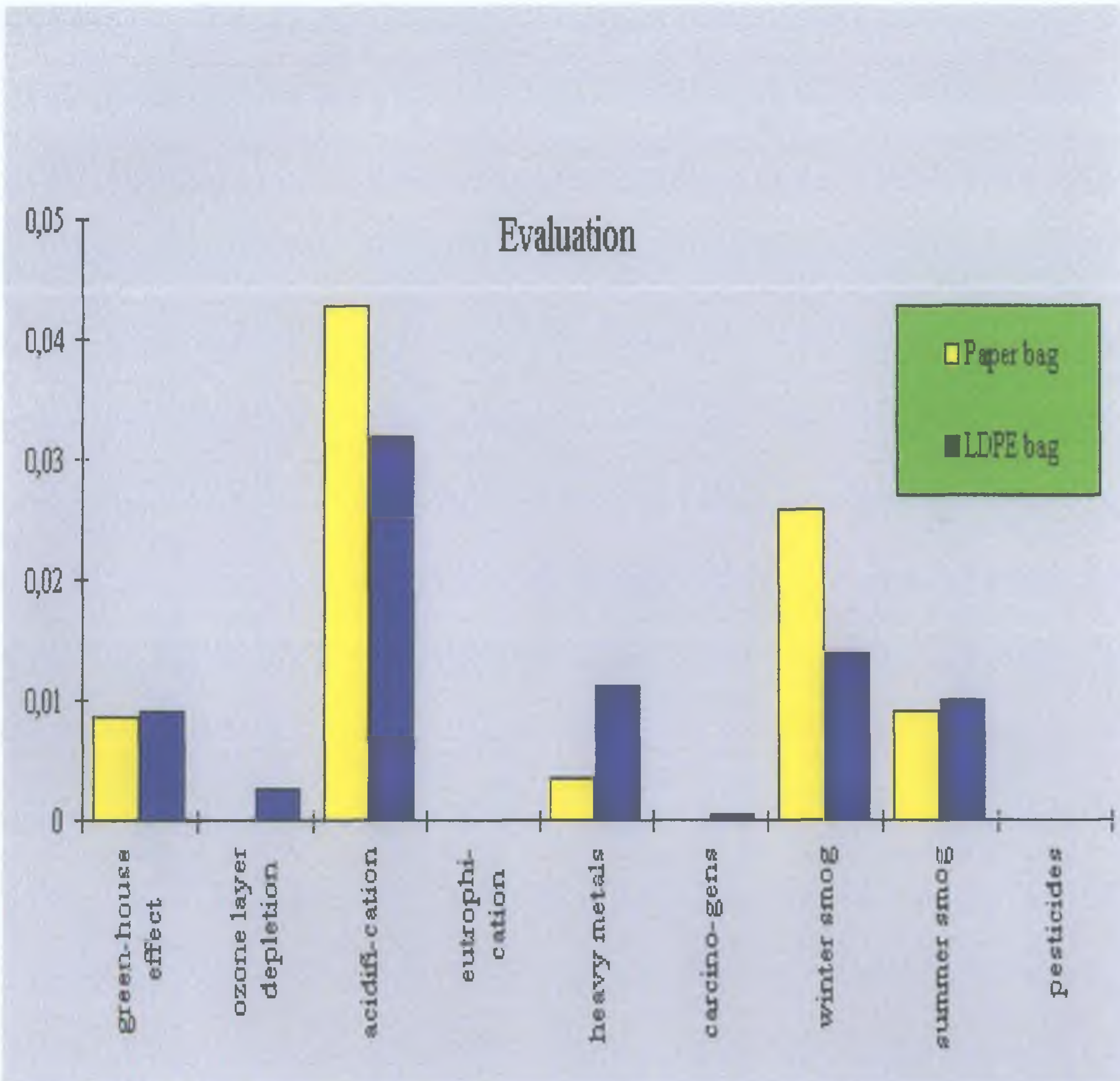
Normalisation stage in life cycle impact assessment



Source: Simapro 3.1

APPENDIX VII

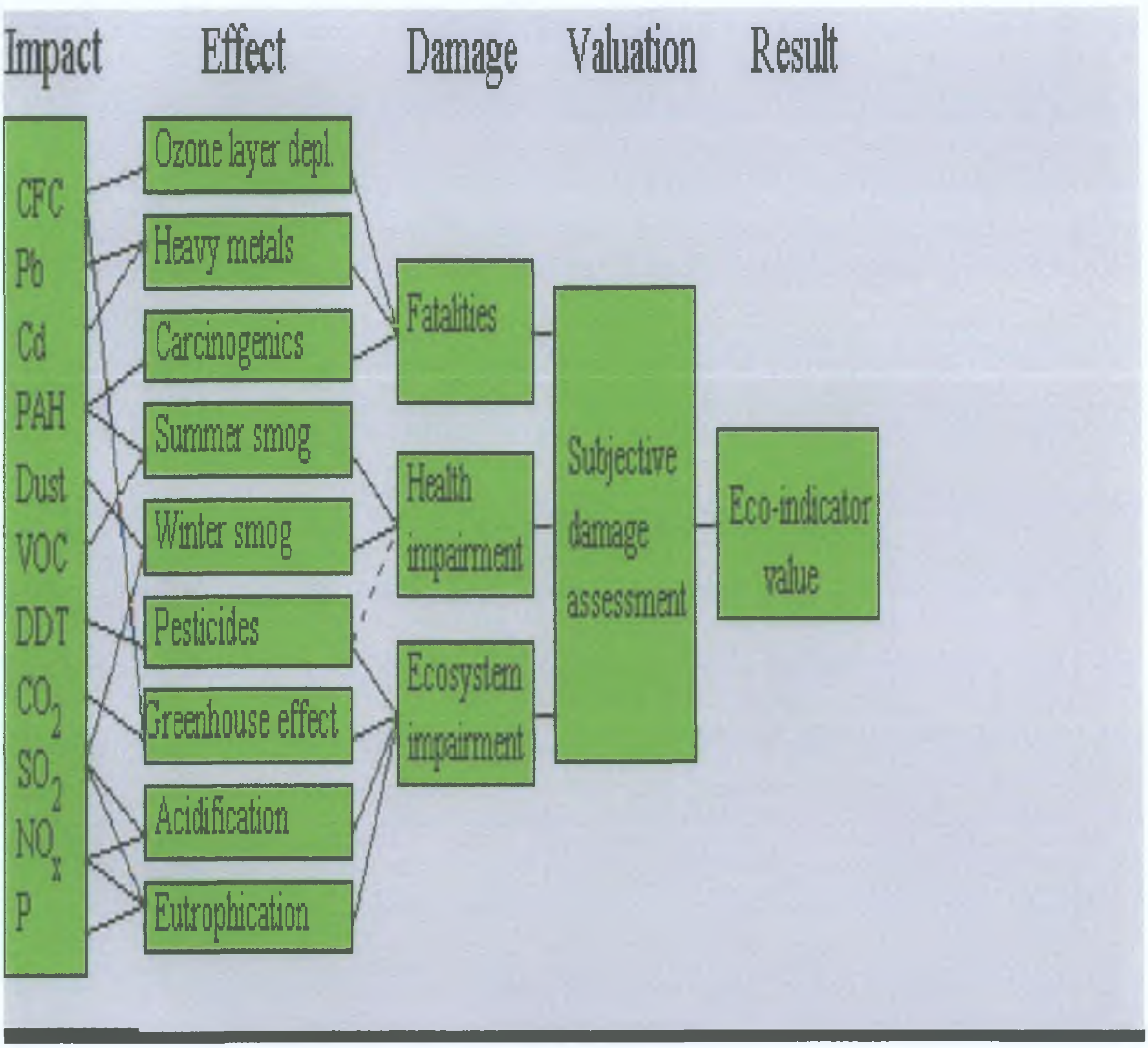
Evaluation stage in life cycle impact assessment



Source: Simapro 3.1

APPENDIX VIII

Eco-indicator Criteria



Source: Eco-indicator 95 Manual for Designers.

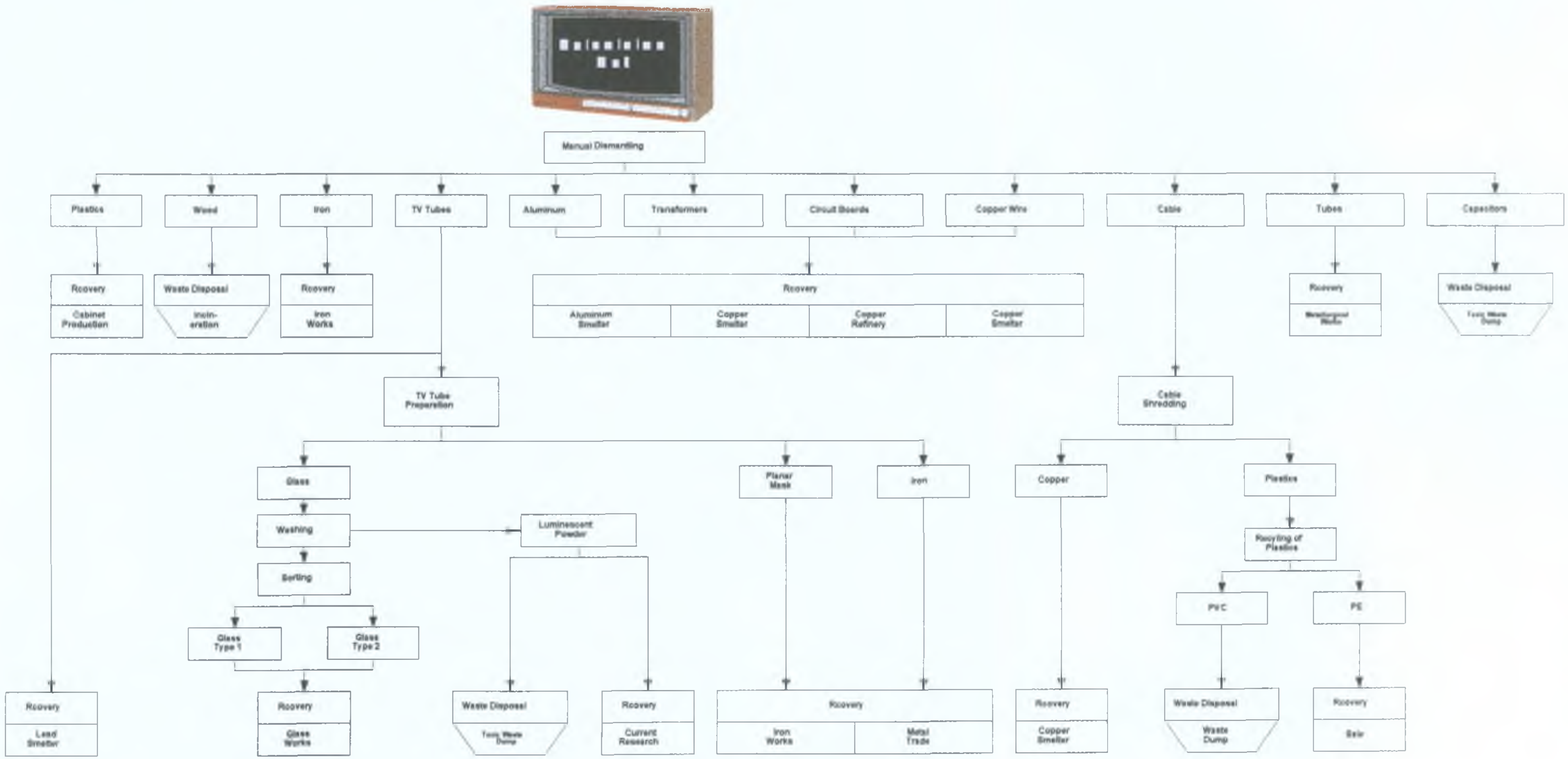
APPENDIX IX

Disposal of End-of-Life Electrical and Electronic Equipment in Germany (Oct. 1996)

Branch/Association	**IT-Industry (VDMA/ZVEI)**	**CE-Industry (ZVEI)**	**White Goods-Industry (ZVEI)**	**Communication-Tech. Industry**
Lean Ordinance	Draft of BMU (20.02.96, hearing on 26.03.96)	no draft	no draft	BMU (German Ministry for the Environment) wants to have communication technology equipment covered by IT ordinance (Concerned industry associations will merge in the first half of 1997)
Self Commitment of Industry	CYCLE concept (02.10.95, compromise paper with all actors of 14.06.96)	ECORETURN (01.03.96, incl. proposal of lean ordinance)	Disposal and recycling concept for big appliances (23.09.96)	
Curb-side Collection by	*Community* (withdrew from compromise 10/96) => private service	Community and private services	Systems organised by manufactures and others in open competition	
Responsibility for Cost of Collection	*Community as representative of consumer*, last owner	Community as representative of consumer	Consumer / Last owner	
Recycling / Utilisation by	Manufacturer, certified recycler in open competition	Certified recycler in open competition	Manufacturer, certified recycler in open competition	
Responsibility for Cost of Recycling	Manufacturer (cost included in sales price)	Consumer / Last owner	Consumer / Last owner	
Old Appliances (Sold before enactment of ordinance)	Responsibility for cost of recycling at consumer	Treatment like new appliances	Treatment like new appliances	

APPENDIX X

Components of a Television Set



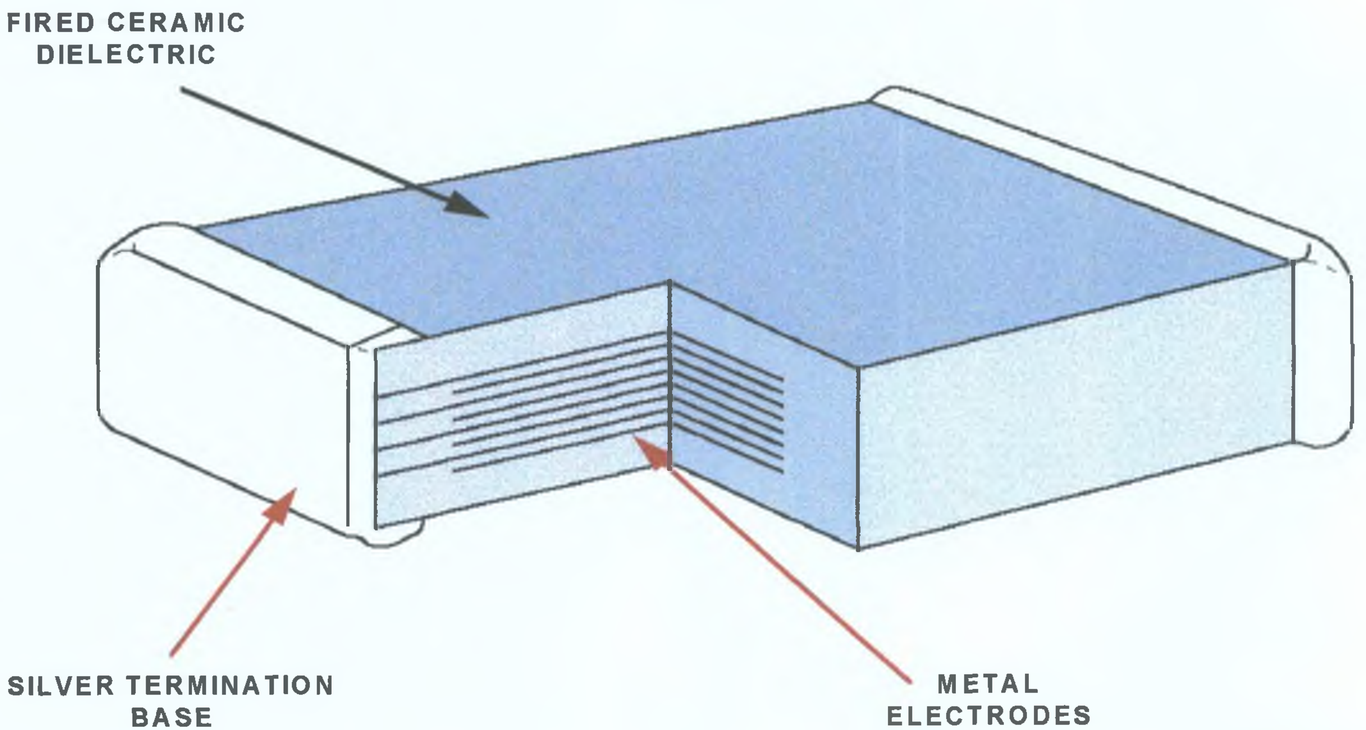
Source: HER Recycling GmbH

APPEDIX XI

VARISTOR TECHNOLOGY

Multilayer

Quality First



HARRIS
SEMICONDUCTOR SECTOR