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Practical Environmental Advice for Business

GG427

Sustainable design of electrical and electronic products to control costs and comply with legislation

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"The Waste Electrical and Electronic Equipment (WEEE) Directive and the Restriction of Use of Certain Hazardous Substances (ROHS) Directive have potentially serious consequences for the costs and profitability of most UK electronics companies. This Guide contains practical advice and guidance to help reduce these costs and is an important step towards improving the environment in which our members do business."

Information Technology Telecommunications and Electronics Association (INTELLECT)

"In addition to outlining the regulatory requirements, this Guide highlights the wider business threats and opportunities, and the tangible cost savings and business benefits that companies can achieve through sustainable product design."

Institution of Electrical Engineers (IEE)

"Designers and engineers are in an ideal position to ensure that sustainable design is applied at the concept stage. This Guide is written specifically to facilitate the upstream design decisions that are critical to the generation of economically, environmentally and socially sustainable patterns of production and consumption."

Institution of Mechanical Engineers (IMechE)

"Applicable to large and small companies throughout supply chains in the electrical and electronics sector, this Guide provides an excellent starting point for designers and will help stimulate innovative approaches to sustainable product design which will save money and reduce environmental impact."

Smiths Group plc

"Illustrated throughout with practical and effective examples, this Guide is a valuable tool to help UK electrical and electronics companies maintain their competitive advantage through sustainable product design."

Plextek Ltd

Summary

Sustainable design aims to minimise the costs and environmental impacts of a product over its entire life-cycle. Improving resource productivity - producing more goods and services with fewer inputs of materials and utilities, and with less pollution and waste - will reduce business costs and benefit the environment.

The main issue driving electrical and electronics companies to consider sustainable product design is compliance with two new items of EC legislation:

- Directive on Waste Electrical and Electronic Equipment (WEEE);
- Directive on the Restriction of Use of Certain Hazardous Substances (ROHS) in electrical and electronic equipment.

Estimated costs to the UK economy to comply with these Directives are:

- **£120 million/year** over ten years for capital costs and research and development costs to comply with the ROHS Directive;
- **£217 - £455 million/year** to comply with the WEEE Directive;
- **£55 - £96 million/year** for increased operating costs from using alternative substances to comply with the ROHS Directive.

Sustainable product design can reduce these costs and deliver additional business benefits. Designers have a key role to play in helping companies to:

- adopt best practice techniques which could help UK companies save £205 million/year - £116 million from reduced manufacturing costs and £89 million from reduced end-of-life costs;
- gain competitive advantage from functionality and service innovation;
- achieve business benefits from environmental marketing and enhanced reputation.

This Good Practice Guide, which is applicable to all sizes and types of company in the electrical and electronics industry, provides practical advice and guidance for designers. It describes the regulatory requirements and business opportunities and explains how to:

- manage sustainable product design within companies and across supply chains;
- select more environmentally friendly materials and mechanical design;
- reduce the environmental impact of electrical and electronic design.

The Guide contains a worksheet for sustainable product design, and information about **free** advice and publications available to designers and others through the Environment and Energy Helpline on **0800 585794**.

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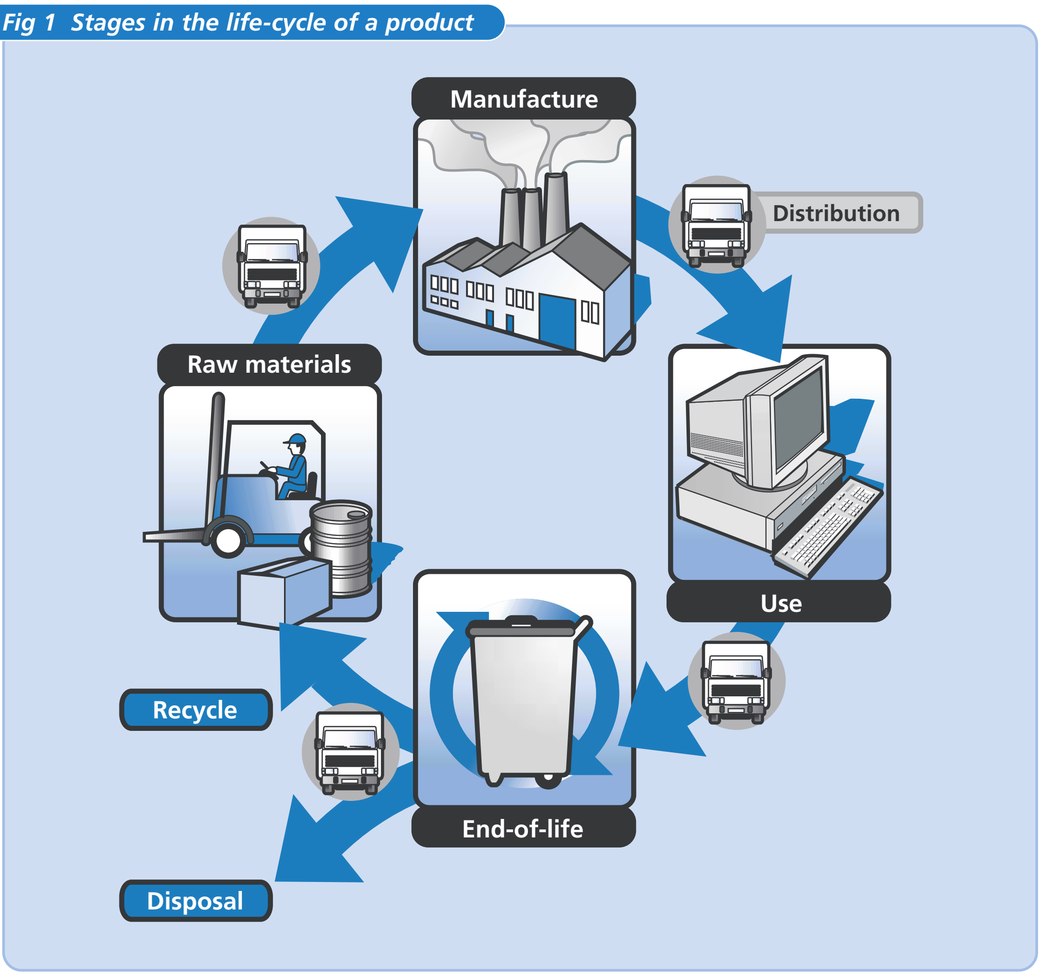
Introduction

Sustainable design takes into account the costs and environmental impacts of a product over its entire life-cycle (see Fig 1).

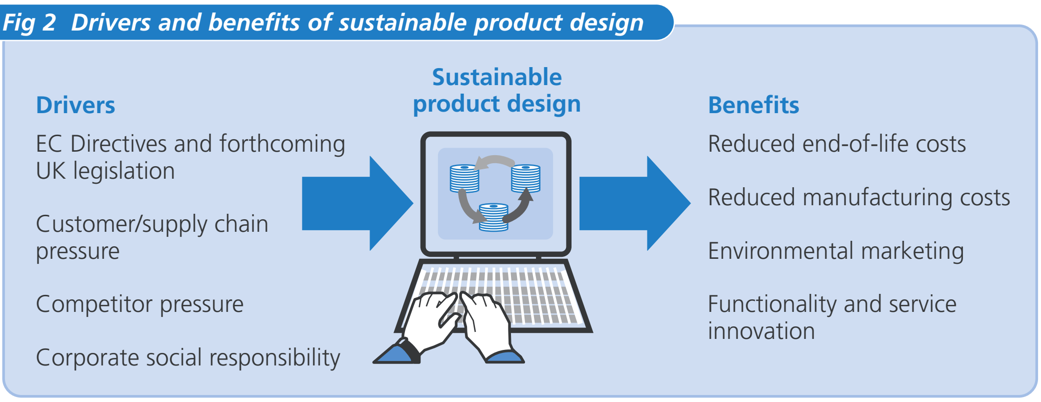
Fig 1 Stages in the life-cycle of a product



Sustainable design aims to minimise these costs and environmental impacts. Improving resource productivity - producing more goods and services with fewer inputs of materials and utilities, and with less pollution and waste - will reduce business costs and benefit the environment.

The main drivers for sustainable product design and the benefits that companies can achieve are summarised in Fig 2.

Fig 2 Drivers and benefits of sustainable product design



Impact of legislation on life-cycle costs

From August 2005 and July 2006 respectively, all companies, large and small, producing electrical and electronic products, components and sub-assemblies have to comply with two new items of EC legislation:

- Directive on Waste Electrical and Electronic Equipment (WEEE);
- Directive on the Restriction of Use of Certain Hazardous Substances (ROHS) in electrical and electronic equipment.

The WEEE Directive will require producers to pay for at least the collection of their products at end-of-life from central points and meet targets for re-use, recycling and recovery. The ROHS Directive means that products containing restricted substances will have to be redesigned or withdrawn by July 2006.

Challenge for designers

Both Directives will increase costs for UK producers. Some manufacturers and suppliers may be able to absorb a proportion of these costs. However, the EC has calculated that even these producers will need to raise prices by 1 - 4% unless they take action now to reduce the costs of compliance.

By adopting sustainable design principles, designers can play a key role in:

- minimising the costs of meeting the Directives' requirements;
- achieving additional business benefits for their companies.

The market leaders have already taken action to redesign their products and, in some cases, have set up end-of-life product recovery schemes that cover the costs of compliance and show a net profit to the producer.

Improving resource productivity

The Design Council agrees that at least 80% of the quantities and costs of materials and utilities required to manufacture electrical and electronic products are locked in at the design stage. The goals of sustainable design are to improve resource productivity by:

- minimising the use of materials and utilities;
- eliminating the use of hazardous materials, to facilitate re-use and recycling;
- maximising functionality and service life;
- generating zero waste and pollution;
- maximising the re-use of components and sub-assemblies and recycling of materials at end-of-life to meet original product standards.

Business benefits

In addition to saving money, sustainable product design can also deliver additional, less tangible business benefits, including:

- **Environmental marketing.** Many customers now include sustainable product design issues in tender documentation and a 'greener' image can increase market share.

- **Enhanced reputation.** Demonstrating good environmental performance can enhance the company's standing with shareholders, investors and other stakeholders.
- **Improvements in workplace health and safety.** For example, through reduced waste and emissions.
- **Increased staff morale.** There is a growing awareness among staff that businesses must play a role in working towards sustainable development - this can provide a strong personal incentive to pursue sustainable product design.

1.1 The purpose of this Guide

This Guide provides practical advice and guidance to designers to help them apply sustainable product design within companies and across supply chains to:

- reduce the costs of compliance with the WEEE and ROHS Directives by reducing manufacturing costs and end-of-life costs;
- secure additional business benefits for their company through environmental marketing, and functionality and service innovation.

The Guide includes:

- industry examples highlighting the benefits of different approaches and techniques;
- a worksheet for sustainable product design;
- contact details for the mentoring group involved in its preparation.

Regulatory requirements

2.1 Waste Electrical and Electronic Equipment Directive

The WEEE Directive encourages the design and production of electrical and electronic equipment to facilitate its repair, possible upgrading, re-use, disassembly and recycling at end-of-life. From August 2005, it makes producers[1] in ten broad product categories responsible for financing the collection of their own products at end-of-life and meeting targets for re-use, recycling and recovery (see appendix 1).

New products must be marked clearly with the producer's name together with a symbol (crossed-out wheelie bin) to indicate that it must not be disposed of in municipal waste collection. Producers will be required to provide information on components and materials used in their products to enable treatment facilities, re-use centres and recycling facilities to disassemble, re-use and recycle them. Producers will also be required to provide information to treatment facilities to identify specific components and materials in the equipment that must be removed, including:

- capacitors containing polychlorinated biphenyls;
- components containing mercury (eg switches, backlighting lamps);
- batteries;
- printed circuit boards (PCBs) in mobile phones and those greater than 10 cm^2;
- brominated flame retardants (will be banned from use after July 2006 by the ROHS Directive);
- cathode ray tubes (fluorescent coating must be removed);
- gas discharge lamps (mercury must be removed);
- liquid crystal displays.

The annual cost to UK electronics producers to comply with the WEEE Directive is estimated at £217 - £455 million (see Table 1)[2].

Table 1 Estimated annual costs of compliance with the WEEE Directive

	Estimated annual cost to UK producers
Separate collection of WEEE	£26 - £98 million
Dismantling and treatment of WEEE	£98 - £207 million
Meeting re-use, recycling and recovery targets	£52 - £114 million
Marking products for separate collection	£18 million
Providing information to treatment and recycling facilities	£7 million
Reporting compliance information to Environment Agency	£11 million
Total	**£217 - £455 million**

Legal compliance issues are discussed in appendix 1 and detailed information about the WEEE Directive is available at www.dti.gov.uk/sustainability.

1 Producers are defined as any company that manufactures affected electrical or electronic equipment, resells equipment produced by other manufacturers under their own brand, or which imports such equipment.

2 Based on data in DTI Partial Regulatory Impact Assessment of WEEE Directive, March 2003. Overall costs will depend on how much WEEE is collected.

2.2 Restriction of Use of Certain Hazardous Substances Directive

The ROHS Directive is complementary to the WEEE Directive and seeks to reduce the environmental impact of WEEE by restricting the amount of certain hazardous substances that may be present in products to certain maximum concentration levels. It applies to the same categories of products defined by the WEEE Directive, with the exception of medical equipment systems and monitoring and control equipment. From July 2006, producers will need to demonstrate that their products do not contain more than the maximum permitted levels of[3]:

- lead;
- mercury;
- cadmium;
- hexavalent chromium;
- polybrominated biphenyls (PBB) and polybrominated diphenyl ethers (PBDE), which are currently used as flame retardants.

It is proposed that the levels are 0.01% by weight for cadmium in any individual homogenous material and 0.1% for the other substances.

To demonstrate compliance, producers may have to undertake extensive and time-consuming surveys of their suppliers of components and sub-assemblies. The UK Government is hoping, however, to establish a compliance scheme whereby verification of a company's products is demonstrated through the adoption of industry-led standards supported by agreed testing methods where appropriate. In turn, first tier suppliers may require materials information from their suppliers, and so on down the supply chain.

Where restricted substances are currently in use, the greatest costs could arise from the need to develop, test and re-qualify products, components and sub-assemblies to meet performance specifications and standards. This will have a considerable impact on supplier contracts throughout these supply chains and will require extensive awareness-raising and communication.

The estimated annual cost and one-off costs to comply with the ROHS Directive are shown in Table 2 overleaf.

3 A limited number of exemptions for specific applications in some product categories are listed in the Annex to the ROHS Directive. Use of spare parts to repair equipment put on the market before 1 July 2006 will be permitted.

Table 2 Estimated costs to comply with the ROHS Directive[4]

Item	Estimated one-off cost between 2003 and 2006	Estimated annual cost
Research and development costs to develop, test and requalify products, components and sub-assemblies using alternative substances.	£810 million	
Capital costs of retooling lead-use equipment (eg the substitution or refurbishment of solder bath machines and surface mount ovens).	£480 million	
Higher annual operating costs due to increased costs of alternative substances, use of greater quantities, increased energy consumption (particularly for available alternatives to lead solder) and lower process efficiencies.		£38 million

Detailed information about the ROHS Directive is available at www.dti.gov.uk/sustainability.

The implication of not knowing what is in individual components and sub-assemblies means that products may have to be taken off the market by July 2006.

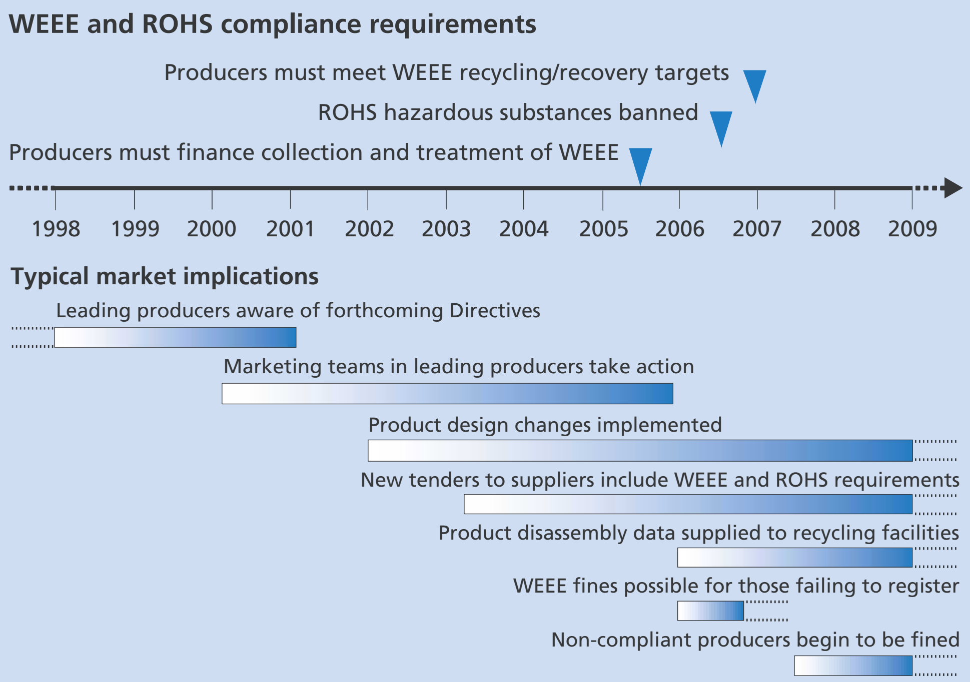
2.3 Timescales for design decisions

Minimising the costs of compliance with these Directives will require companies to make significant changes to the design of their products at the earliest opportunity. Design decisions made at the start of the product design process have a knock-on effect throughout the design process. Therefore, the cost of implementing these design changes can be reduced by planning ahead and making key design decisions as early as possible. This also allows maximum opportunity to consult customers and suppliers about the proposed changes, and take on board their requirements and suggestions.

To some companies, requirements under the Directives that need to be met in 2005 and 2006 may seem a long way off. But closer inspection of the typical market implications of these Directives shows that this is not the case (see Fig 3).

4 Based on data in DTI Regulatory Impact Assessment of ROHS Directive, March 2002.

Fig 3 Typical market implications for compliance with WEEE and ROHS



To maintain their competitive advantage, many of your leading customers and competitors began assessing the potential market implications of these Directives in the mid-1990s. By the time that proposals for these Directives were adopted by the European Commission in June 2000, many marketing teams in leading companies had already taken action. Product design changes followed soon after, and information is already being provided to recycling facilities to assist them to disassemble products for recycling and recovery at end-of-life.

Preparations at BT

BT spent a year educating its engineers, buyers and suppliers about WEEE and ROHS and building a database of hazardous substances used in over 20 000 products. It is agreeing phase-out dates with its major suppliers for the substances and selected alternative technologies.

In November 2002, BT introduced a pre-tender process which required all potential suppliers of products, sub-assemblies and components to provide information on:

- how they will demonstrate compliance with the WEEE and ROHS Directives;
- a timetable for phase-out of restricted substances;
- what take-back schemes the supplier will operate for end-of-life products, sub-assemblies and components collected by BT;
- what re-use, recycling and recovery rates the supplier will achieve for products, sub-assemblies and components, to ensure that BT meets its WEEE obligations.

If you have not already begun to prepare, you need to take action as soon as possible to catch up with the market leaders.

Sustainable product design in Japanese electronics companies

Legislation on sustainable product design and end-of-life recycling was implemented in Japan in 2000 (see appendix 2). Japanese electronics companies are already ahead of the rest of the world in sustainable product design, and the international nature of the industry means that sustainable design and recycling criteria will affect specification and procurement criteria worldwide.

The new laws are already starting to affect UK companies supplying and designing products for the European plants of Japanese manufacturers.

Business opportunities

3.1 Reducing end-of-life costs

The starting point for reducing end-of-life costs is to understand what causes the user to discard the product and what then happens to it. This will help you to identify the best end-of-life option and make design changes. It is best to adopt a simple approach which can be adapted easily to changes in future market conditions.

Choosing the best end-of-life option

Options that avoid the product becoming waste in the first place will generate the greatest economic and environmental benefits. Information will be required from many different parts of the company, in particular:

- marketing staff, to understand how the customer currently uses and discards the product;
- sales staff, to calculate the annual weight of products sold;
- technical staff, to assess how the product, components and sub-assemblies could be re-used, recycled and recovered at end-of-life.

Design tip: send new product samples to recyclers

Some Japanese manufacturers are gaining valuable end-of-life design advice by sending new product samples to recycling facilities. The recyclers assess the ease of product disassembly and the cost benefits of recycling its materials. This information is fed back to product designers to help them decide on materials and assembly options.

Information about recyclers operating in your area is available at www.esauk.org/directory.

It is important to consider whether:

- The product is intrinsically suited to a particular end-of-life option. For example, if a product's commercial value lies in the packaged technology it contains, then product re-use, upgrading or refurbishment may be better end-of-life options.
- The end-of-life option makes good business sense and can be integrated into the overall marketing strategy for the product.
- Suitable collection, transport and storage arrangements exist or can be put in place for getting equipment back in sufficient quantities and conditions for the end-of-life option.

Take-back scheme for mobile phones

Telecoms and electronics recycler, Shields Environmental, has introduced a scheme to tackle the 15 million mobile phones being scrapped each year in the UK as users upgrade to new models. UK network service providers and several leading retailers now encourage customers to return used phones through a 'Fonebak' programme, using freepost envelopes or in-store promotion.

As the returned phones are processed, Shields Environmental will track and record the details and provide reports to help organisations track their phones and comply with the WEEE Directive, including:

- breakdown of phones received;
- sales destination, quantities and revenues received for re-use of products or components;
- final destination, quantities and revenues received for materials recycling;
- overall re-use and recycling rates.

Phones that are suitable for re-use are refurbished and tested prior to re-marketing to developing countries. Phones which are not suitable for re-use are dismantled, valuable components are extracted for resale and materials are sent for recycling.

Optimising product design for end-of-life

Having identified the most appropriate end-of-life option, you can consider making product design changes to gain the greatest cost savings. Examples of design considerations applicable to different options are highlighted in Table 3. The options are ranked from those with the greatest benefits down to the least cost-effective. The design considerations are discussed in detail in sections 5 and 6.

Table 3 Examples of design considerations for different end-of-life options

End-of-life options	Examples of design considerations
Durable products to extend product lifetime	Consider using higher specification components to provide greater reliability
Re-use of whole products, for example, by resale to secondary markets	Easy to change logo identity - easy to refurbish exterior
Upgrading, for example, to update the product with the latest technology	Modularisation by function
Refurbishment by replacing failed components and sub-assemblies	Embedded sensors and spare memory in controllers used to store product lifetime data for fault diagnosis
Extraction of components and sub-assemblies for re-use	Modules and sub-assemblies designed to be tested independently
Extraction of materials for recycling	Sub-assemblies easy to separate by material type, eg break-away sections
Extraction of materials for energy recovery in a power plant	Sub-assemblies with high calorific value easily separated
Disposal to landfill	Hazardous materials easily separated for disposal as hazardous waste

Potential cost savings from recycling printed circuit boards

A study by Envirowise in 2002 found that about 6 600 tonnes of PCBs from high value products (eg computers, telecommunications and other IT equipment) manufactured by UK producers reach end-of-life each year and are discarded in the UK. With current recycling technology and materials prices, these PCBs are worth about £2/kg to recycle, equivalent to £13 million/year. Re-use of high-grade components could net more than £60/kg, equivalent to an additional £76 million/year.

Arrangements with suppliers, customers and recyclers

Consultation and collaboration between suppliers, producers, customers and recyclers is essential to ensure the successful implementation of the desired end-of-life option.

Collaboration with recycler generates net cost savings for producer

As part of its plan to upgrade 35 000 payment terminals throughout the UK, Barclaycard requires its supplier, Ingenico Fortronic in Dunfermline, to collect the old payment terminals and arrange for recycling.

Old payment terminals are sent to CCL (North) Ltd, a specialist recycling facility in Irvine. Here, the terminals are completely dismantled and recycled. The plastics are segregated and recycled, and the metals are recycled. CCL has a unique process for recycling the printed circuit boards. The individual chip components (ICs) can be removed from the boards, refurbished and re-marketed. Some of the components are sold to Ingenico for use in the manufacture of new terminals for supply to Barclaycard and other parts are sold worldwide for use in different applications. There is no charge made to Barclaycard or Ingenico for recycling.

In recent years, some large OEMs have put increasing pressure on their suppliers to share some of the products' warranty costs. For example, most OEMs now expect the supplier's two-year warranty on components and sub-assemblies to start on the date when the customer puts them into its products rather than the date when they are sold to the customer. Building on this approach, some OEMs are starting to put pressure on their suppliers to take back their components and sub-assemblies at end-of-life as part of the price package, and arrange for them to be re-used, recycled or recovered.

3.2 Reducing manufacturing costs

The Design Council agrees that at least 80% of the quantities and costs of materials and utilities required to manufacture electrical and electronic products are locked in at the design stage. Sustainable product design techniques can assist companies to redesign their products so that smaller quantities are used in the manufacturing process, thereby generating significant cost savings.

Reducing cost and improving functionality at Varian Medical Systems UK Ltd

Varian Medical Systems opted for sustainable redesign of its radiotherapy simulator collimator unit and is now achieving:

- £162 000/year in components and materials cost savings;
- a 65% reduction in the number of components used per collimator;
- a reduction of 29% in the number of fasteners and a 27% reduction in assembly time;
- easier equipment disassembly for recovery and recycling.

"The sustainable product design approach has proved to be a real eye-opener, taking away preconceptions and resulting in products with significant cost savings and better functionality."

John Peel, Business Development Director, Varian Medical Systems UK Ltd

Potential cost savings from improved design of PCBs

The Envirowise study in 2002 estimated the annual manufacturing cost of PCBs, which are fabricated and assembled in the UK, at about £2.3 billion. Section 6 highlights that, by consulting fabricators and assemblers earlier in the design process, designers could considerably reduce these costs. For example, optimising PCB sizes to maximise the number of boards that can be made from a single panel can reduce waste off-cuts to less than 15%. On the other hand, poor sizing of PCBs can lead to over 50% wastage in off-cuts. Adoption of best practice design for manufacturing techniques could reduce fabrication and assembly costs by at least 5%, equivalent to £116 million/year, and there is scope for significantly more savings.

3.3 Environmental marketing

Sustainable product design can also help companies to increase their market share by tapping into the growing number of 'green' consumers. Customers in the public sector are increasingly requiring suppliers to address sustainable product design issues in tendering exercises. For example, from January 2003, the NHS purchasing and supply specifications require suppliers of electrical and electronic equipment to demonstrate how they will manage their products at end-of-life to facilitate recycling and recovery. Other commercial customers, particularly for large business-to-business contracts, have also indicated that they want producers to demonstrate adequate control over future end-of-life product costs.

Many OEM producers, particularly in consumer supply chains, have published environmental policy commitments. To comply with these commitments, they are exerting pressure on their supply chains by:

- dealing only with suppliers that have a certified environmental management system (EMS) such as ISO 14001[5] or EMAS;
- asking their suppliers to demonstrate that they manufacture their products, components or materials in an environmentally responsible manner.

Some suppliers have turned this supply chain pressure to their advantage, by offering sustainable product design advice on the sub-assemblies they manufacture for these customers.

5 Available from BSI, Tel: 020 8996 9000, Fax: 020 8996 7001.

Advice builds customer relationships

CHK makes bespoke sub-assemblies with a high technical and test input. Realising that one large customer appeared unaware of the WEEE and ROHS Directives, CHK saw it as an opportunity to strengthen their relationship with them and was invited to discuss the implications with the European Engineering Director. CHK is now helping the customer to redesign the sub-assembly to reduce the costs of compliance.

In consumer electronics, some companies have gained increased market share and profitability by advertising the lower running costs of their products. Meanwhile, the Japanese electronics industry is using sustainable product design and end-of-life recycling legislation to reduce the industry cost base and develop competitive positioning in export markets.

Environmental marketing strategy boosts profits

A marketing strategy based on the sale of more energy- and water-efficient appliances was launched by Electrolux in 1994. By reducing consumer running costs, Electrolux can sell its 'Green Range' products at a higher price. In 2002, the Green Range accounted for 16% of European sales, with a 22% gross profit - better than average margins. Green Range products have also delivered an above average increase in market share compared to other Electrolux products.

Eco-labelling can provide marketing benefits by highlighting that the product is designed specifically to reduce its overall environmental impact, compared to other similar products. The International Standards Organisation (ISO) distinguishes three main approaches to eco-labelling and these are discussed in appendix 3.

Extending the product lifetime

Designing a product so that it can be easily serviced and upgraded to extend the product's lifetime can also provide marketing benefits and enhance brand value. It will also reduce the cost of repairing products that fail quality control inspections or are returned under warranty. This involves:

- Considering higher specification components, sub-assemblies and PCBs to provide greater product reliability.
- Designing parts for equal lifetime, since failure of a single part often means that the whole product is discarded.
- Designing for disassembly to ensure that products can be taken apart efficiently.
- Modularisation to enable product upgrade and repair.
- Ensuring replaceable and upgradable components have easy accessibility.
- Considering how best to supply spares. Providing spares in kits may result in waste of unwanted parts. However, having each part available separately may increase packaging requirements.

Marketing opportunity to increase customer contact

Black Box AV specialises in designing, building and installing specialist audio and video systems for commercial and public sector organisations. The product design is modular, allowing easy upgrade to extend product life. The company has identified the WEEE Directive as a marketing opportunity to contact its customers every year to ask them if they are planning to replace or upgrade the equipment, whilst also reminding them to use the end-of-life collection scheme provided by Black Box.

3.4 Functionality and service innovation

Sustainable product design can stimulate innovation and lead to radical changes in the product itself. Focusing on the service that the customer gains from the product and how the customer uses the product's functions can provide a fresh insight into new ways of delivering these.

If the customer simply wants to use the service provided by the product, then perhaps leasing is the best way forward. The on-going income stream provided by selling services can be advantageous to a company's business model compared to the occasional sale of goods.

'Pay-per-wash' service for households

In November 1999, Electrolux and the electricity supplier, Vattenfall, set up a limited trial scheme in Gotland, Sweden. Customers could buy a 'clean clothes' service without having to own a washing machine. Customers 'borrowed' a washing machine free of charge from Electrolux, which was connected via an 'intelligent' electricity meter and the internet to a central database that read the meter and tracked the machine's use. In the trial, customers paid 72p per wash cycle. The charge was made through their electricity bill. With such a service, at end-of-life the machine would be taken back for remanufacturing or used for spare parts by Electrolux. Electrolux is now evaluating the project.

Reviewing how the customer uses the product's function can identify opportunities to design products to gain functional leadership in the marketplace. For example, a multifunctional product such as a combined printer, scanner and copier machine can increase market share by meeting customer requirements in a more cost-effective manner. In this case, the combined printer, scanner and copier:

- uses fewer materials and is cheaper to manufacture than three separate machines;
- uses 70% less energy in stand-by mode;
- takes up much less space (a benefit to both the seller and the buyer);
- costs less to transport and retail.

Such machines need to be more robust to provide greater reliability because if they do break down the user loses all three functions. Manufacturers may also offer rapid replacement contracts which generate extra income and provide peace of mind to customers.

Managing sustainable product design

4.1 Integrating sustainable design into the product development process

Sustainable product design can be incorporated into the product development process by addressing:

- people - raising awareness of sustainable product design at the concept stage and then providing a continual reminder throughout the process;
- processes - checklists to capture sustainable product design improvement opportunities and ensure they are addressed throughout the design process;
- techniques - disseminating good design tips and ideas.

Sustainable product design issues should be considered as early as possible in the design process. Time invested at the concept and feasibility stages will pay dividends and avoid the need for more expensive design changes later in the design process. The feasibility stage leads to the production of design specifications which provide the framework requirements for the detailed design. These should be clearly defined at an early stage and should involve consultation with all relevant business aspects and external stakeholders.

Well-researched design specifications optimise the potential competitive advantage and reduce the risk of needing expensive changes later in the design process.

Key staff in the team should be given training on sustainable product design issues, approaches and tools. In addition to keeping your design systems hardware and software up to date, all members of the product development team should be encouraged to keep up with latest developments in their fields. For some, this may be part of the continuing professional development required for their professional qualifications. For example, electronics designers should keep abreast of the latest design tools, eg design for manufacture (DFM) checking systems for CAD.

Where in-house expertise/resources are lacking it will be worth obtaining help from consultants and other experts, eg a university. In some cases, such help can be obtained through Envirowise or through subsidised local schemes[6]. You may want to create an information hub in your company to signpost to guidance, advice and tools for sustainable product development, and to encourage dissemination of good design tips and ideas, eg through case study examples.

6 Further details are available from your local Business Link on 0845 600 9006.

Intranet database of tools, benchmarks and guidelines

Electrolux decided to support its sustainable design programmes by creating an information database on the company's intranet. The database signposts to company policies, sustainable design guidelines, tools, minimum product requirements and reports analysing legal requirements and market trends. A List of Restricted Materials is used to avoid banned or debated substances and Environmental Design Guidelines focus on issues such as simplifying the product design, reducing material diversity, labelling parts, ensuring easy disassembly and incorporating recyclable materials.

To stimulate further improvements, the company regularly benchmarks the sustainable design performance of all of its products. A 'Fleet Average' indicator is calculated for each product range by assessing factors such as energy and water consumption. The 'Green Range' indicator is used to measure the profitability of Electrolux products with leading environmental performance.

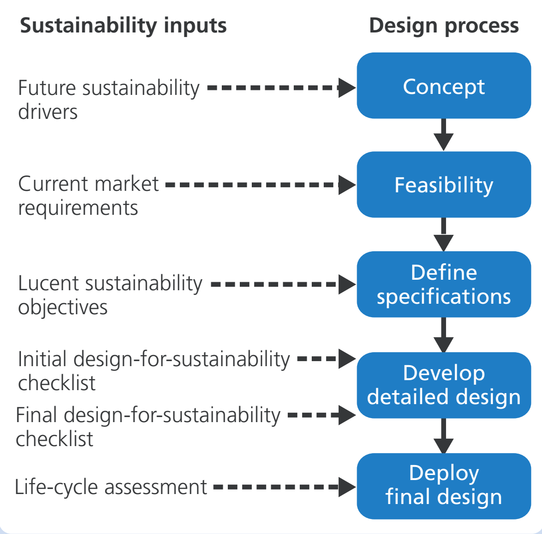
Many companies choose to address sustainable product design through policy statements in their environmental management systems, quality management systems or business excellence models. Most companies make commitments to continual improvement of product design, but often leave it up to the professional experience and knowledge of the designers to implement. The practical advice and guidance on sustainable product design contained in this Guide can provide a useful framework to support designers in working towards these policy commitments. The management systems can then be used to set practical objectives, implement management programmes and evaluate the results achieved through audits and management reviews. This can provide a useful mechanism to maintain momentum for sustainable product design.

Systematic approach to integrating sustainable product design into the design process

Lucent Technologies Mobility Solutions, designers and suppliers of hardware equipment for mobile phone companies, has benefited from adopting a systematic approach to integrating sustainable product design into its design process (see Fig 4). This involved integrating six sustainability inputs with existing design processes and amending the gates at the end of each stage to include checks that the relevant issues have been considered.

Future sustainability drivers and technology opportunities are analysed to identify trends to feed into the concept stage. Particular attention is paid to current and proposed EC Directives and regulations in the USA and China which will affect global markets. Current market requirements for particular countries and customers are considered at the feasibility stage, eg some customers specify that packaging must not contain PVC, or prohibit the use of certain plasticizers.

Fig 4 Integrating sustainable product design into the design process



Lucent's corporate sustainability objectives enter into the design process at the product definition phase, which produces the design specifications. Particular attention is focused on:

- material content - avoiding substances which are banned by Lucent (this goes beyond current regulations for banned substances);
- energy consumption;
- product waste;
- re-usability at end-of-life;
- materials recyclability at end-of-life (eg numbers and types of materials, quantities of materials, use of surface treatments);
- emissions during product use (eg noise, heat).

Design-for-sustainability checklists focus on specific aspects of product design. They are completed at the start of the detailed design stage and again at the end of this stage to account for any refinements to the specifications. The checklists cover six key aspects:

- energy consumption;
- batteries;
- plastic parts;
- PCBs;
- hardware and wired sub-assemblies;
- packaging.

For some products, a life-cycle assessment is carried out on the final design to measure the improvement in performance compared to the base-line design, and to identify target areas for future product development. The overall operation and performance of the sustainable design approach is managed through a product based environmental management system (EMS) which is certified to ISO 14001.

4.2 Issues within the business and along the product life-cycle

As with any design changes, sustainable product design can have upstream and downstream impacts on suppliers, customers and recyclers, and can impact on a wide range of business issues including:

- purchasing;
- manufacturing;
- distribution;
- marketing;
- quality;
- health and safety.

It is important to ensure that these impacts are identified and addressed as early as possible in the design process. This will vary depending on which stage of the product's life-cycle the design improvements are focused. For example, design decisions focused on using less materials may mainly affect quality, manufacturing and purchasing, whereas design decisions to use more environmentally friendly materials in the manufacturing process will also require consultation with suppliers and health and safety. Changes to product packaging will require consultation with customers, whereas design for materials recycling at end-of-life will require consultation with recyclers.

It is also important to consider how design changes will affect other stages in the product's life-cycle. For example, materials chosen to reduce cost in the manufacturing process may decrease opportunities for end-of-life re-use or recycling, and so reduce the overall cost savings that could be achieved across the entire product life-cycle. A fastener which facilitates product disassembly for re-use and recycling at end-of-life may require more labour to install.

You can use the worksheet in appendix 4 to assess the benefits of design improvements on different aspects within and outside the business.

4.3 Design for manufacture

It is worth focusing particular attention on design for manufacture. Designing products to minimise manufacturing and assembly costs involves:

- elegant simplicity - simple design is good design;
- consultation with component suppliers, assemblers and PCB fabricators.

Designing-in elegant simplicity takes more experience and is more challenging, but repays effort many times over with greater long-term profitability and reliability. For example, using a smaller number of higher function components will reduce the number of components to be joined and the complexity of the fixings. As well as reducing manufacturing costs, this will reduce failure rates in assembly and use.

Complexity is expensive! Simplifying the product design will significantly reduce manufacturing and assembly costs.

Fabrication and assembly analysis

Involving all parts of the supply chain in the product development process is essential to minimise production costs. Tendering high level specifications earlier in the design process can enable suppliers to provide valuable design-for-manufacture (DFM) advice, while still ensuring competitive quotations. This will enable the suppliers to influence the detailed design to reduce manufacturing and assembly costs. Early involvement of suppliers will also remove the risk of costly last-minute design changes, eg to address critical design errors.

Many designers, however, only contact their suppliers after the detailed designs have been approved for manufacture. This often leads to increased lead-time, cost and environmental impact through wasted materials.

Materials and mechanical design

5.1 Design to minimise resource consumption

The first consideration is to use fewer materials and utilities over the product's life-cycle and generate less waste. A simpler design with fewer components can reduce material and assembly costs while also improving reliability, as there will be fewer items that could fail. In some cases, multiple parts can be designed into one part.

Designers can use engineering principles to minimise the use of resources, including:

- Defining realistic requirements for stiffness and strength.
- Optimising part dimensions, for example, using finite element analysis.
- Where stiffness is required, consider alternatives to thick-walled sections, such as ribbed structures, bosses, supports and hollow structures using gas-assisted injection moulding.
- Selecting the most appropriate materials for the product life-cycle. For example, upgrading to a stronger plastic to achieve stiffness will usually require smaller quantities, but may lead to increased manufacturing cost and reduced recyclability at end-of-life.

Minimising the number of different materials used in the product is always beneficial and can deliver cost and environmental benefits. This can reduce manufacturing costs through economies of scale and will increase the potential for materials recycling at end-of-life. It is often possible to manufacture sub-assemblies from only one material and, in some cases, from recycled materials.

5.2 Design for assembly and disassembly

There is a wide range of attachment techniques. The choice of attachment type depends on assembly cost and required performance parameters during the product's lifetime. For example, will the attachment be permanent during the product's lifetime or will it need to be reversible for servicing, repair or upgrade? The choice will affect the purity of recycled materials and hence their value. Reversible attachments need to be accessible, easy to remove and durable, and will give purer materials after disassembly.

Where fasteners are used, it is important to:

- Make fastening points accessible, visible and clearly marked. Consider colour coding to aid assembly and disassembly, eg for upgrade or repair.
- Use a simple component orientation.
- Use screws in place of rivets for easier disassembly at end-of-life.
- Standardise screw heads to aid assembly and disassembly with as few tools as possible.
- Avoid assemblies that require power tools to take them apart.
- Consider using fasteners of the same material as the parts to be joined to optimise materials recycling opportunities at end-of-life.

Snap-fits can be designed to allow rapid and efficient disassembly of the product, eg by ensuring that the tines are easily accessible. However, in some cases they may not provide adequate pressure on connecting parts, for example, to ensure adequate conductive continuity in products requiring shielding from electromagnetic interference, and in areas with high levels of vibration.

Joining of dissimilar materials using adhesives or welding should be avoided. Staking techniques for joining thermoplastic parts to other materials can provide a low-cost approach, but reduce opportunities for end-of-life materials and component recycling.

5.3 Packaging design

Product packaging is a significant business cost for most manufacturing companies. Many companies have redesigned their packaging in recent years and have usually achieved significant cost savings. In addition, they have found it easier to comply with the packaging regulations[7].

Packaging has to protect goods, facilitate handling and distribution, present information and act as a marketing tool for the product. Inadequate packaging can result in product damage, customer returns and wastage. Poor packaging design can even result in injury. In 2000, packaging-related accidents (eg cuts to hands) accounted for more than 67 000 recorded hospital casualties in the UK and cost the National Health Service more than £12 million.

Good design has a vital role to play in producing packaging which is both fit for purpose and environmentally appropriate. Reviewing the materials and design of your product packaging may identify opportunities to:

- design out the need for protection;
- eliminate or reduce your packaging requirement;
- optimise your packaging use, ie matching the packaging to the level of protection needed;
- introduce re-usable transit packaging;
- use recycled materials.

These approaches will deliver cost savings by minimising your consumption of resources and the quantities of waste for disposal.

Computer manufacturer benefits from development of plastic-free packaging

IBM regularly reviews all aspects of its product packaging and initiates many improvements during the course of each year. The redesign of one keyboard delivery box alone has eliminated the use of plastics and saved the company more than £450 000/year.

Until recently, the keyboards were delivered in a corrugated box with expanded polystyrene (EPS) for keyboard protection and with additional EPS to keep the keys firmly in place. This original packaging cost around £1.40/keyboard and, because of the size of the carton, only 36 units could be loaded onto a pallet.

Designers in the UK developed a number of alternatives and ultimately selected a design which uses only corrugated board, with cleverly worked folds and cut-outs. The new slimline box costs 50p and allows 104 keyboards to be loaded onto a pallet. The corrugated board itself is made up of 60% recycled material, while the elimination of plastics facilitates box recycling after use. Other measures, involving re-usable packaging, have brought the total savings from improved packaging design to well over £2 million/year.

7 Further information about the packaging regulations is available from the Environment and Energy Helpline on 0800 585794.

The following Good Practice Guides provide detailed advice and guidance on the above issues and are available free of charge through the Environment and Energy Helpline on 0800 585794.

- GG360 *Packaging design for the environment: reducing costs and quantities*
- GG140 *Cutting costs and waste by reducing packaging use*
- GG141 *Choosing and managing re-usable transit packaging*

5.4 Design for materials recycling

Metals

A large proportion of electrical and electronic equipment is increasingly made out of plastic to reduce manufacturing costs. However, in many cases, current recycling technology either cannot return the plastic to its original performance specification or else it is more costly to recycle the plastic than it is to purchase it from new.

Metal components are more expensive than plastic alternatives, but they are also highly recyclable. In some cases, where plastic components cannot be recycled profitably to meet WEEE Directive targets, it may make good business sense to make greater use of metals. To reduce costs, reverting to metal would require companies to improve their product designs to make components and sub-assemblies thinner, smaller, lighter or less numerous, and to maximise opportunities for component re-use. New metal alloys are being developed which may offer additional end-of-life benefits compared to plastics.

Future techniques for automated disassembly using shape-memory materials

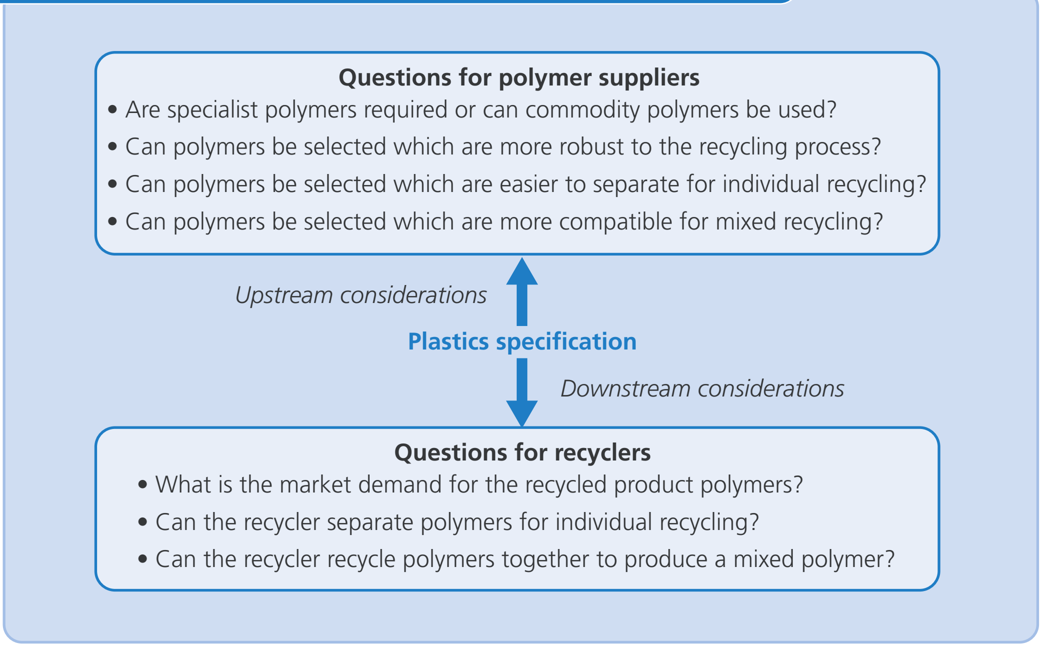
Shape-memory alloys can be plastically deformed at a relatively low temperature, and upon exposure to a higher temperature will return to their previously defined shape or size. Several pilot projects have used this property for rapid disassembly of mobile phones using ovens or lasers to heat shape-memory alloy fasteners.

Although there are several shape-memory alloys, only those that can generate significant force are of commercial interest, such as the nickel-titanium (Ni-Ti) alloys and copper-based alloys, eg copper-zinc-aluminium (Cu-Zn-Al) and copper-aluminium-nickel (Cu-Al-Ni). The Ni-Ti alloys have greater shape-memory strain (up to 8% versus 4 to 5% for the copper-based alloys), tend to be much more thermally stable, have excellent corrosion resistance and have much higher ductility. On the other hand, the copper-based alloys are much less expensive (Ni-Ti costs about £150/kg whereas Cu-Zn-Al costs about £30/kg), can be melted and extruded in air with ease, and have a wider range of potential transformation temperatures. Some plastics also exhibit shape-memory effects and are available at similar prices, when purchased in bulk, to conventional engineering plastics.

Plastics

Selecting the best choice of plastics for your product involves considering upstream material flows with the materials suppliers and downstream end-of-life issues with recyclers. This is illustrated in Fig 5.

Fig 5 Upstream and downstream issues affecting choice of plastics



Each of the main polymer types has different strengths and weaknesses in environmental and performance terms[8]. Discussions with materials suppliers should ascertain whether it is necessary to use a specialist polymer (such as engineering plastics or high performance plastics) for the product or whether a commodity polymer would suffice (appendix 5 contains abbreviations for commonly used plastics). Commodity plastics (eg polypropylene, polycarbonate and polyurethane) are generally cheaper and may provide greater security of supply compared to specialist plastics. There is also likely to be a greater market demand for recycled commodity plastics than recycled specialist plastics. Many materials suppliers provide technical helplines which can provide advice on supply and demand questions such as these.

Where possible, plastics that are more robust to the recycling process should be used. It is also important to consider the design of the injection moulding process. For example, some design features (eg sharp corners) and process steps (eg heating profiles) can degrade polymers and so reduce the quality of the plastic for recycling.

Ideally, the same plastic polymer should be used throughout the product. This will provide economies of scale from purchasing larger quantities and also increase opportunities for end-of-life recycling. In some cases, there may be opportunities to use both virgin polymer and the same type of recycled polymer for different parts of the product. This will not affect recycling value at end-of-life and may offer cost savings. Mixing different types of plastic at end-of-life recycling often produces a poorer quality plastic overall, with less recycling value.

If this is not possible, it may be preferable to select polymers which are easier to separate at end-of-life for individual recycling. This will depend on the recycling process (eg granulation followed by air filtration) and require consultation with the recyclers.

Alternatively, you should select combinations of polymers which can be recycled together to form a usable alloy. For example, polycarbonate (PC) and ABS can be recycled together to form PC/ABS. The compatibility of different combinations of polymers for recycling is compared in Table 4.

8 Further information is available from the IdeMat database (www.io.tudelft.nl/research/dfs/idemat/index).

Table 4 Compatibility of different polymer combinations for recycling[9]

	LDPE	LLDPE	ULDPE/VLDPE	Ethylene copolymers	HDPE	PP	EPM/EPDM	PS (gen purpose, high impact)	SAN	ABS	PVC	PA	PC	PMMA	PBT	PET	SBS
LDPE																	
LLDPE	1																
ULDPE/VLDPE	1	1															
Ethylene copolymers	1	1	1														
HDPE	1	1	1	1													
PP	4	2	(1)	2	4												
EPM/EPDM	4	4	(1)	3	4	1											
PS (gen purpose, high impact)	4	4	4	4	4	4	4										
SAN	4	4	4	4	4	4	4	4									
ABS	4	4	4	4	4	4	4	4	1								
PVC	4	4	4	(2)	4	4	4	4	2	3							
PA	4	4	4	(1)	4	4	(1)	4	4	4	4						
PC	4	4	4	4	4	4	4	4	2	2	4	4					
PMMA	4	4	4	(3)	4	4	4	4	2	2	2	4	2				
PBT	4	4	4	(2)	4	4	4	4	4	4	4	4	1	4			
PET	4	4	4	(3)	4	4	4	4	4	4	4	3	1	4	3		
SBS	4	4	4	4	4	4	4	1	3	2	3	3	4	4	4	4	

Key: 1 excellent; 2 good; 3 fair; 4 incompatible; (n) dependent on composition

Identify plastic polymers

Plastic polymers should be marked with the material category and date of manufacture to optimise opportunities for materials recycling at end-of-life. Flexible tooling using tool inserts allows in-mould marking to be changed if the polymer material is changed. ISO 11469[10] specifies a system of uniform marking of plastic products and the symbols and abbreviations to be used are given in ISO 1043[10]. For example:

- >ABS< identifies an ABS polymer;
- >PC+ABS< identifies a blend where PC is the main polymer;
- >PVC-P(DBP)< identifies a PVC containing dibutyl phthalate as plasticizer.

A separate set of codes and symbols are used to identify plastics used in packaging[11].

9 Further information is available at www.bpf.co.uk.

10 Available from BSI, Tel: 020 8996 9000, Fax: 020 8996 7001.

11 Further information is contained in GG360 *Packaging design for the environment: reducing costs and quantities,* available free through the Environment and Energy Helpline on 0800 585794.

Select compatible labelling, adhesives and coatings

Unless labels and adhesives are compatible with the moulding polymer for recycling, they should be avoided. The information can be moulded on to a product using a different surface finish to increase visibility (eg dimpled) or laser printed directly on to the moulded part. Painting, electroplating and conformal coatings of different materials should also be avoided. If an adhesive with recycling compatibility is not available, ultrasonic welding, heat staking and spin welding, hot-plate or hot-gas welding should be considered.

5.5 Available alternatives to hazardous substances

In general, it is advisable to avoid all hazardous materials where possible. Where this is not practical, the materials should be clearly marked and easy to separate.

The ROHS Directive restricts the use of lead, mercury, cadmium, hexavalent chromium, PBB and PBDE from July 2006. It applies to the same categories of products defined by the WEEE Directive, with the exception of medical equipment systems and monitoring and control equipment.

Other hazardous materials used in electrical and electronic equipment are also under scrutiny and may be subject to voluntary or regulatory restrictions in the future.

Lead

Lead is widely used in solder to attach components to PCBs, and is also used in glass for cathode ray tubes and light bulbs.

For most mainstream soldering applications, alloys based on tin-silver-copper (Sn-Ag-Cu) will probably be the first choice to replace lead solder. However, Sn-Ag-Bi type alloys are likely to be used for surface mount consumer products and Sn-Cu solders may be developed for wave soldering where cost is an important consideration.

Because of the higher melting points of these lead-free solders, there are implications for every stage in the PCB manufacturing, assembly and testing process. The simultaneous phasing out of brominated flame retardants means that the issue of flammability at the higher working temperatures will be critical. Many replacement flame retardants have a lower temperature range.

Compatibility of lead-free solders with existing components and coatings must also be considered. A range of components - from plastic encapsulated devices to capacitors, LEDs, electromechanical components and connectors - may not be able to withstand the higher process temperatures required for lead-free solders. Although thermal stress on components is being addressed through soldering flux and equipment developments, some components will need to be requalified to withstand higher temperatures, which is time-consuming and expensive. There may also be some impact on component lifetimes.

These issues are discussed in detail in:

- *Lead-free soldering: update 2000,* available from the DTI website (www.dti.gov.uk/publications).

Further information is also available at www.npl.co.uk, www.lead-free.org and www.smtuk.demon.co.uk.

Brominated flame retardants

Flame retardants are added to polymers used in electrical and electronic products to ensure that they meet international standards such as UL 94[12]. Typical applications and polymers used in the electronics industry are summarised in Table 5.

Table 5 Applications and polymers used in the electronics industry

Application	Polymers used
Laminated PCBs	Epoxy, phenolic, polyamides
Encapsulants for electronic components	Epoxy
Housings for electrical and electronic equipment	ABS, HIPS, PC, nylons
Switches, sockets and connectors	PET, PBT, polyamides
Wire and cable insulation	PVC, EVA, XLPE

Traditionally, the electronics industry has preferred to use brominated flame retardants such as TBBPA. However, a number of halogen-free flame retardants are now commercially available. Some of the main alternatives which are applicable to different polymer types used in the electronics industry are summarised in Table 6.

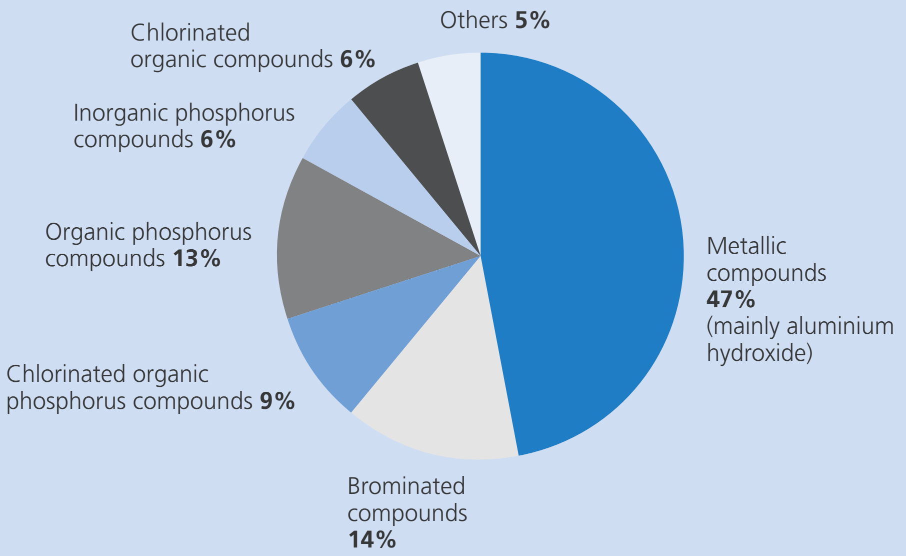
Table 6 Halogen-free flame retardants applicable to different polymer types

Halogen-free flame retardant	Applicable polymer types
Aluminium trioxide	Epoxy, ABS, HIPS, PC, EVA, XLPE
Magnesium hydroxide	Epoxy, ABS, HIPS, PC, nylons, PVC, EVA, XLPE
Magnesium carbonate	ABS, HIPS, PC, PVC, EVA, XLPE
Zinc borate	Epoxy, nylons, PVC, EVA
Zinc hydroxystannate	PVC, EVA
Zinc stannate	Epoxy, nylons, PVC
Red phosphorus	Epoxy, phenolic, nylons
Ammonium polyphosphate	Epoxy
Phosphate esters	Phenolic, ABS, HIPS, PC, PVC, EVA
Melamine derivatives	ABS, HIPS, PC, nylons
Reactive P-N	Epoxy

To give an indication of the relative popularity of these flame retardants, Fig 6 analyses the commonest types of flame retardant used in Swedish-made products in 1999.

12 More information is available at www.ul.com/plastics/flame.html.

Fig 6 Flame retardants used in Swedish-made products in 1999[13]



Surveys of products sold in Sweden indicate that the use of halogenated flame retardants in electronic consumer product casings was almost completely eradicated by 1998[14]. Attention has subsequently been focused on electrical wiring and PCBs. A comprehensive analysis carried out by the Electronic Industries Association of Japan in 1999[15] estimated that about 3% of global PCB manufacture had switched to using halogen-free materials. However, it expects this to increase rapidly to 50% by 2005 and 80% by 2010. For many of these alternatives, recent trials have demonstrated an increase in PCB production yield compared to using traditional brominated flame retardants.

Further information is available from www.halogenfree.org and www.itri.co.uk.

Cadmium

Cadmium is used by industry for a number of purposes, including:

- as an anti-binding agent (cadmium-plated parts have good lubricity);
- as an anti-corrosive agent (particularly to protect connectors and fixings in salt-spray conditions where electromagnetic compatibility (EMC) is a critical issue);
- as pigments and stabilisers in paints and plastics;
- as solders.

In many cases, design changes could remove the need for cadmium coatings altogether. Where coatings are required, alternatives to cadmium are available for most applications and include:

- tin and its alloys;
- zinc and its alloys (eg zinc/cobalt);
- ion vapour deposition (aluminium coatings);
- nickel;
- epoxide;

13 KEMI Product Register (www.kemi.se).

14 *Phase-out of PBDEs and PBBs: Report on Governmental Commission*, Swedish National Chemicals Inspectorate, March 1999.

15 *Japan Jisso Technology Roadmap 1999*, Electronic Industries Association of Japan, August 1999.

- plasticised coatings that have been developed for specialised use.

Where weight is not an issue, nickel/aluminium/bronze alloys can be used for corrosion resistant connectors. These alloys may increase the weight of each connector by a factor of 2 - 3 or greater in comparison with cadmium-plated aluminium connectors. New materials continue to be developed, many of which exceed the performance of existing cadmium coatings.

Nickel-PTFE plating process outperforms cadmium plating

As a replacement for cadmium plating of lightweight aluminium components used in aerospace electrical interconnects, Icore International has developed a proprietary nickel-PTFE plating process which offers superior corrosion protection.

Nickel offers an excellent combination of electrical, mechanical and corrosion protection properties for barrier protection of aluminium electrical interconnects. However, thin nickel plating is porous and allows the aluminium to be rapidly attacked. The nickel-PTFE process eliminates the nickel porosity for thin layers and delivers up to three times the corrosion protection of cadmium plating, while also providing superior abrasion and impact resistance.

Further information is available from www.sea.org.uk and www.bcf.co.uk.

Hexavalent chromium (chrome VI)

Chrome VI is used in:

- chrome-based alloys or chrome plating to provide hard wearing surfaces;
- corrosion resistant surface treatments;
- pigments and stabilisers in paints - lead chromate pigments are used to achieve bright yellows, oranges and reds.

Where coatings are required, alternatives to chrome VI that may be considered include:

- zinc-based coatings and compounds, eg zincate;
- nickel-based coatings, eg electroless nickel, boron nickel;
- copper;
- silver;
- modified primer/paint technologies.

Further information is available from www.sea.org.uk and www.bcf.co.uk.

Mercury

Mercury was traditionally used in:

- thermostat switches (eg in domestic heating systems);
- tilt switches (eg for convenience lighting in car boots and chest freezers, and for pilot lights on gas ovens).

Most manufacturers phased out the use of mercury in these applications in the early 1990s. Today, there are drop-in replacements for these components which do not use mercury.

Small amounts of mercury are used in fluorescent lights and discharge lamps.

Electrical and electronic design

Section 4.3 highlighted that choosing a simple, robust design will deliver improved product profitability and reliability. Regular consultation with component suppliers, PCB fabricators and assemblers is also essential to reducing manufacturing and assembly costs.

6.1 Components

For electrical and electronic design, the starting point is component specification because this has knock-on effects on other production issues. The packaging of components has a major impact on the design of PCBs and their ease of assembly. Some components are available with a range of packaging options. Where design constraints allow, maximising the feature geometry will make the PCB easier to manufacture and assemble, thus reducing costs. Of course, designers must check that components do not contain substances that will be banned under the ROHS Directive.

Reprogrammable components can keep the product design more flexible and enable design upgrades without needing to change hardware requirements. This can be particularly cost-effective for low volume products where hardware set-up costs are a major component of product cost. In addition, reprogrammable components can improve time to market by allowing for programming changes at the last minute or in the field. Reprogrammable components also offer greater opportunities for re-use at end-of-life.

6.2 PCBs

Once the component specification has been agreed, the design rules provided by fabricators and assemblers should be used to guide the PCB design. In addition to ensuring that the design is capable of being manufactured, the design rules contain actions that will optimise yield and reduce cost at the fabricator and assembler. Although these will vary, depending on particular fabrication and assembly processes, they generally involve actions such as maximising hole sizes, making tracks and gaps bigger and reducing the number of layers. Design for ease of testing and rework in the assembly process is also an important aspect of good PCB design. The designer should agree the testing process to be used with the assembly house and design the PCB to facilitate simple, quick and effective testing.

In practice, however, many PCB designs received by fabricators require significant amounts of rework to enable them to be manufactured. The PCB is often the last item to be designed and yet one of the first items needed in production and so there is considerable pressure for fast turnarounds. But surveys by the Printed Circuit Interconnection Federation highlight that more than 25% of all jobs received by PCB fabricators have critical errors from design rule infringement. Poor routing on the circuit board is a particularly common problem. Designs are often set up requiring minimum track widths and gaps between them. Often, this is an unnecessary level of technical complexity and a better designed board provides equivalent performance while increasing the tolerances available to the manufacturing process. A further 25% of PCB jobs lack important design information, eg incomplete or missing files or instructions.

‘Right first time’ design will minimise costs and avoid production delays.

Some designers may perceive that DFM checking of the approved design is part of the service provided by the PCB fabricator, but there are considerable disadvantages in taking this approach. On a superficial level, it may appear attractive as a way of saving time in the short term. However, leaving DFM checking to the fabricator will increase costs for the customer and the vendor, and will introduce additional delays that may have significant effects on time to market.

As well as the time costs of referring design amendments back to the customer for approval, designs with errors or which require reverse engineering for DFM checking are more likely to be delayed in favour of better designed jobs, which represent higher profit margins and lower risk to PCB fabricators. To save time, some fabricators may decide to make design changes without consulting the designer, particularly for inner layers. However, it is very important for the designer to capture any design amendments as they may impact on future design revisions.

There are considerable benefits from carrying out DFM checking at the design stage, including:

- fewer revision spins, faster time to market and improved product quality;
- reduced fabrication and assembly costs, and avoided risk of expensive redesigns;
- maintaining data ownership at the designer.

The CAD design tools currently used by designers check the electronic functionality of the PCB design, but most do not include DFM checking. In this case, designers should consider investing in DFM software which can be added onto their CAD design system[16]. A flexible output format will enable rapid data exchange between customer and vendor. Most PCB fabricators use ODB++ for their tooling software and many offer reductions in tooling costs if the design output is supplied in this format.

Although the DFM software is supplied with a generic set of fabrication and assembly design rules, designers are strongly recommended to customise the software with the design rules for their individual fabricators and assemblers. This is particularly important when moving from prototype manufacturers to volume manufacturers, who may use quite different process techniques. For example, PCBs fabricated as prototypes may use labour-intensive techniques which can become prohibitively expensive in volume manufacturing.

Significant cost and environmental benefits in the production of single layer PCBs are detailed in Case Study 430 *Offset lithography cuts costs and waste in PCB manufacture*, available free of charge through the Environment and Energy Helpline on 0800 585794.

6.3 Connections

Options for component and PCB connections include:

- standardising connector types to aid assembly;
- design modules and sub-assemblies to be independently testable;
- plug-in boards to aid assembly and disassembly;
- making high value components surface mount or socket fit to aid removal from units that fail QA inspection and to facilitate component re-use at end-of-life;
- grouping hazardous materials and components together on the PCB and incorporating perforated ‘snap lines’ so that they are easy to break off for separate disposal at end-of-life.

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16 Information and advice about DFM software are available from the Electronic Design Realisation Centre (www.edrcentre.org.uk).

6.4 Power requirements

For many electronic products, the energy consumed during the products' lifetime represents a significant proportion of the overall costs of product ownership. Designing products with lower energy consumption provides tangible cost savings to customers and can be exploited as a valuable marketing benefit. Where the product features energy efficient operating modes, consumers can be encouraged to use these by providing 'user friendly' controls and easy-to-follow user instructions.

Electronic products can be designed to minimise energy consumption and costs during use by:

- using low voltage logic;
- designing an energy efficient 'stand-by mode';
- making the product compatible with other energy efficient devices;
- increasing the thermal tolerance of the design to avoid the use of cooling fans or air conditioning;
- improving the insulation of hot or cold elements;
- looking at recovery of excess heat output (if a product is used in an air-conditioned building, between 1.2 and 1.6 times the heat output of the device will be used to remove that heat from the building).

Further information on the energy efficiency of electrical and electronic products is available from DEFRA's Environmental Product Information Consortium (www.ukepic.com).

Batteries

Where batteries are required, you should consider using batteries with greater energy efficiency and lower environmental impact. Nickel metal hydride (NiMH) is a well-established technology that offers more than twice the volumetric energy density (energy stored within a given volume) of cheaper nickel cadmium (NiCd) batteries. NiMH batteries are smaller, lighter and contain less heavy metal content. Lithium ion (LiON) batteries offer still higher energy density, using a newer technology that became commercially viable in 1992. The batteries are becoming standard on most high-end mobile phones and are taking over the market from NiMH.

The Batteries and Accumulators Regulations[17] were implemented in response to EC Directives and apply to batteries containing specified amounts of mercury, cadmium or lead. The regulations:

- banned the marketing of batteries with over 0.0005% of mercury by weight, with the exception of button cells or batteries containing button cells, where the limit is 2% of mercury by weight;
- require that appliances using batteries must be designed to ensure that the batteries can be easily removed;
- introduced a marking system for batteries to specify mercury, cadmium or lead content and indicate separate collection for disposal as hazardous waste at end-of-life.

[17] Further information about the Batteries and Accumulators (Containing Dangerous Substances) (Amendment) Regulations 2000 is available from www.hmso.gov.uk.

In late 2003, the EC presented a proposal for a new directive aimed at the collection and recycling of batteries and accumulators. The draft, which is likely to be finalised around the end of 2004, has a number of key proposals including, four years after entry into force:

- at least 160 g per head of population per year of portable consumer batteries to be collected;
- of this 160 g, at least 90% to enter a recycling process with a minimum target of 55% material recycling and within this, at least 80% for NiCd batteries;
- Member States must ensure a collection infrastructure is set up to achieve a high collection rate;
- all automotive batteries to be collected and recycled.

Help available from Envirowise

Designers can obtain free advice and information on sustainable design techniques and cleaner technology from Envirowise.

Envirowise's **free** services include:

- advice from experts through the Environment and Energy Helpline;
- guides, case studies, fact sheets and CD-ROMs which provide in-depth information on sustainable design and cleaner technology issues across a wide range of industry sectors;
- on-site sustainable design reviews (design**track** visits) by Envirowise advisors to help companies identify and implement design improvements;
- seminars and practical workshops to examine how sustainable design techniques can be applied to companies.

These services are available through the Environment and Energy Helpline on 0800 585794 or via the Envirowise website (www.envirowise.gov.uk).

7.1 Free sustainable design review

Small to medium-sized companies (fewer than 250 employees) can request a free, confidential visit from a sustainable design advisor. The advisor will spend up to a full day on site to analyse one of your products, identify cost-effective redesign improvements and develop a practical action plan. The advisor will need to take your product and packaging apart and, preferably, also disassemble one of your competitor's products as a benchmark. To get the best from the visit, you should invite a range of staff to participate, eg a design engineer, marketing staff and top management.

To book a sustainable design review, phone the Environment and Energy Helpline on 0800 585794 and ask for a design**track** visit.

7.2 Free publications

The publications listed below represent only a small fraction of the wide range of guides, case studies, fact sheets and CD-ROMs available free of charge through the Environment and Energy Helpline on 0800 585794. Alternatively, they can be downloaded from the Envirowise website (www.envirowise.gov.uk).

- *Cleaner product design: an introduction for industry* (GG294)
- *Cleaner product design: examples from industry* (GG295)
- *Cleaner product design: a practical approach* (GG296)
- *Cleaner technology: an essential guide for industry* (GG288)

Compliance issues for the WEEE Directive

Guaranteeing the future costs of WEEE for equipment sold in Europe

From August 2005, producers who wish to market electrical and electronic equipment in any EC Member State will have to guarantee that future costs for the collection of WEEE from central collection points and onward treatment and recycling costs will be met, even if the company ceases to trade. They can do this by a variety of routes which might include joining a scheme for financing WEEE, by taking out 'recycling insurance', or opening a bank account where the money deposited is only released to pay for managing WEEE. Leading insurance companies are currently developing appropriate schemes and setting prices for insurance premiums.

Financing collection of WEEE and meeting recycling/recovery targets

From August 2005, producers have to finance collection of household WEEE from central collection points (eg local authority recycling centres). Producers selling to commercial customers must provide for collection, treatment and recycling of old products on the sale of new products. For products placed on the market after 2005, business-to-business sales must be covered by appropriate contractual arrangements between parties for recovery and recycling.

Priority should be given to repair, upgrade and re-use of whole appliances for original purpose, for example, using a product leasing approach. Where this is not appropriate, producers must arrange for target levels of re-use, recycling and recovery of WEEE components, materials and substances to be met by December 2006 (see Table 7). Producers can choose to meet their obligations either individually or by joining a collective scheme.

For the purposes of calculating these targets, producers or third parties acting on their behalf will have to keep records on the weight of all WEEE entering treatment facilities and the weight of:

- whole appliances which are re-used for their original purpose (this does not count towards meeting re-use, recycling and recovery targets);
- components, sub-assemblies and consumables re-used for their original purpose or recycled;
- WEEE where energy is recovered in a power plant;
- remaining WEEE which is disposed of to landfill.

A calculator to assist companies to assess their compliance with the targets is shown in Fig 7.

Table 7 Minimum end-of-life re-use, recycling and recovery targets set by the WEEE Directive

Product category[18] (See the WEEE Directive for a full range of items in each category)	Component, material and substance re-use and recycling by average weight per appliance	Rate of recovery[19] by average weight per appliance
Large household appliances (eg fridges, washing machines, electric ovens)	75%	80%
Small household appliances (eg vacuum cleaners, toasters, irons, clocks, scales)	50%	70%
IT and telecommunication equipment (eg computers, photocopiers, telephones)	65%	75%
Consumer equipment (eg televisions, video recorders, hi-fi equipment)	65%	75%
Lighting equipment (eg fluorescent lamps, discharge lamps)	80%	N/A
Electrical and electronic tools (eg drills, sewing machines, lawnmowers)	50%	70%
Toys, leisure and sports equipment (eg video games and consoles, train sets)	50%	70%
Medical equipment systems (eg radiotherapy equipment, pulmonary ventilators)	No target has been set	No target has been set
Monitoring and control equipment (eg thermostats, control panels)	50%	70%
Automatic dispensers (eg drinks machines)	75%	80%

18 Applies to products with a voltage of up to 1 000 AC and 1 500 DC.

19 Recovery includes energy recovery in a power plant, in addition to re-use and recycling.

Fig 7 Calculator to help companies assess compliance with WEEE target levels

Weight of WEEE collected	A	.....................kg
Weight of whole appliances re-used for original purpose	B	.....................kg
Weight of components, sub-assemblies and consumables which are re-used for their original purpose or recycled	C	.....................kg
Target level of WEEE re-use and recycling	$\frac{C}{A - B}$	.....................%
Weight of WEEE where energy is recovered in a power plant	D	.....................kg
Target level of WEEE recovery	$\frac{D + C}{A - B}$	.....................%

Producers can choose to meet their obligations either individually or by joining a collective scheme. A recent survey by the Industry Council for Electronic Equipment Recycling (ICER) found that IT, telecoms and consumer equipment producers preferred an individual approach, white goods firms favoured a collective system, while small household appliances and tools manufacturers were undecided. Product lifetime is a factor in these considerations. Producers with long product lifetimes are more likely to prefer a collective approach. On the other hand, value retention at end-of-life and the market for refurbished equipment are business reasons why companies in high-value, shorter lifetime products strongly favour an individual approach.

Financing of historical waste

All producers will have a shared responsibility for financing collection and treatment of waste put on the market before August 2005 (to be known as historical waste).

Each producer's part in this responsibility will be calculated on a proportionate basis such as according to market share at the time that the equipment becomes waste.

The Directive allows producers the option to show consumers the costs of collecting and treating historical waste on the sale of new products for up to 8 - 10 years after August 2005.

Member States may provide the option for producers to use a 'visible fee' to show these costs.

The exact method of financing historical waste has yet to be decided. For products put on the market after August 2005, producers will be required to guarantee that future costs of WEEE will be met.

Detailed information about the WEEE Directive is available at www.dti.gov.uk/sustainability.

Legal requirements for sustainable product design in Japanese electronics companies

In Japan, the Law for the Promotion of the Effective Utilisation of Resources (LPEUR, June 2000) makes sustainable product design obligatory for household appliances, computers, photocopiers, mobile phones and other consumer electronic products. Japanese manufacturers have responded by amending their product design procedures to incorporate:

- use of recyclable resources and re-usable parts;
- design for product longevity;
- design for disassembly.

The Japanese Home Appliance Recycling Law (HARL, April 2001) is stimulating significant changes in product design and recycling practices amongst producers of televisions, air conditioning equipment, fridges and washing machines. The law stipulates minimum end-of-life recycling rates (by weight) for these four product categories, which the industry has already exceeded (see Table 8).

Table 8 Product recycling rates and fees charged under HARL

Product category	Minimum recycling rate	Recycling rate currently achieved	Recycling fees charged to consumers
Air conditioners	60%	78%	£17.50
Televisions	55%	73%	£13.50
Refrigerators	50%	59%	£23.00
Washing machines	50%	56%	£12.00

Consumers are required to discard their old appliances to retailers, who are obliged to accept them and can charge a fee of between £2.50 and £12.50 to transport them to the manufacturers and importers for recycling. The manufacturers and importers charge a fee to the consumer to cover the recycling costs, which can range from £12 to £23 depending on the product category. The penalty for non-compliance with this system is a fine of £1 500 for individuals and £0.5 million for companies.

Overview of eco-labelling schemes

The International Standards Organisation (ISO) distinguishes three main approaches to eco-labelling that a company could adopt:

Type I A third party determines whether or not a product meets certain standards and approves the use of an environmental mark for those that do. Table 9 contains details of some of the best known eco-labelling schemes. Principles and procedures for establishing and operating third party schemes such as these are defined in ISO 14024.

Type II Companies and groups can make 'self-declared' environmental claims for products and services, based on their own standards. Although these claims have less market credibility, this is a popular option for manufacturers as it provides more flexibility for them to differentiate their products by focusing attention on particular environmental features. ISO 14021 provides guidance on suitable evaluation methodologies and definitions of terms used in environmental claims, including:

- designed for disassembly;
- extended product life;
- recyclable;
- recycled content;
- reduced energy consumption;
- reduced resource use;
- reduced water consumption.

Type III Life-cycle assessment (LCA) labels provide quantitative environmental information on all stages in a product's life-cycle. ISO Technical Report 14025 is the first step towards developing a certifiable eco-label in this area, and requires a life-cycle assessment to be carried out in accordance with the ISO 14040 series of standards.

Table 9 Third party eco-labelling schemes

Name	Logo	Affiliated countries	Applicable electrical and electronic products	Website
Australian Ecolabel		Australia	Computers, photocopiers	www.aela.org.au
Blue Angel		Germany	Computers, printers, fax machines, calculators, mobile phones, televisions, washing machines, fridges and freezers, dishwashers, dryers, cookers	www.blauer-engel.de
Eco Mark		Japan	Computers, printers, photocopiers	www.jeas.or.jp
Energy Star		USA, Australia, Canada, all EU countries, Japan, Taiwan	Computers, printers, fax machines, photocopiers, televisions, videos, telephones, washing machines, dishwashers, fridges, air conditioners	www.energystar.gov
Environmental Choice Programme		Canada	Printers, photocopiers	www.environmentalchoice.com
Environmental Labelling Programme	KELA	Korea	Computers, printers, fax machines, photocopiers, televisions, fridges, air conditioners, washing machines	www.kela.or.kr

Table 9 Third party eco-labelling schemes (continued)

Name	Logo	Affiliated countries	Applicable electrical and electronic products	Website
EU Eco-label Scheme		All EU countries	Computers, televisions, fridges, washing machines	europa.eu.int
Green Label Scheme		Hong Kong	Computers, printers, washing machines, dryers, dishwashers, fridges, air conditioners	www.greencouncil.org
Green Label Programme		Thailand	Computers, photocopiers, fridges, washing machines, air conditioners	www.tei.or.th
Green Mark Program		Taiwan	Computers, fax machines, printers, photocopiers, televisions, dishwashers, microwave ovens, dehumidifiers	www.greenmark.org.tw
Nordic Swan		Denmark, Norway, Sweden	Computers, fax machines, televisions, videos, hi-fi equipment, freezers, washing machines	www.svanen.nu
TCO Development		Sweden	Computers, printers, photocopiers, fax machines, mobile phones	www.tcodevelopment.com

Worksheet to assess the benefits of design improvements within and outside the business

	Benefits within the business						Upstream and downstream benefits		
Product life-cycle design improvements	**Purchasing** (High/Med/Low)*	**Manufacturing** (High/Med/Low)*	**Distribution** (High/Med/Low)*	**Marketing** (High/Med/Low)*	**Quality** (High/Med/Low)*	**Health and safety** (High/Med/Low)*	**Suppliers** (High/Med/Low)*	**Customers** (High/Med/Low)*	**Recyclers** (High/Med/Low)*
Raw materials eg use less materials, use materials with lower environmental costs, use recycled materials									
Manufacture eg use less materials and energy, produce less waste and pollution									
Distribution eg use less packaging materials, use materials with lower environmental costs, re-use and recycle packaging									
Use eg increase energy efficiency, repair/upgrade to extend product lifetime									
End-of-life eg design for disassembly to make re-use and recycling easier, enable easy separation of materials for recycling									

*Should be quantified using metrics where possible, eg cost/unit of production.

Abbreviations for commonly used plastics

ABS	acrylonitrile-butadiene-styrene
EPM/EPDM	ethylene-propylene monomer/ethylene-propylene-diene monomer
EVA	ethylene vinyl acetate
HDPE	high density polyethylene
HIPS	high impact polystyrene (also known as toughened polystyrene)
LDPE/LLDPE	low density polyethylene/linear low density polyethylene
PA	polyamide (also known as nylon)
PBT	polybutylene terephthalate
PC	polycarbonate
PET	polyethylene terephthalate
PMMA	polymethyl methacrylate
PP	polypropylene
PS	polystyrene
PVC	polyvinyl chloride
SAN	styrene acrylonitrile
SBS	styrene-butadiene-styrene
ULDPE	ultra low density polyethylene
VLDPE	very low density polyethylene
XLPE	cross-linked polyethylene

Contact details for mentoring group

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Envirowise - Practical Environmental Advice for Business - is a Government programme that offers free, independent and practical advice to UK businesses to reduce waste at source and increase profits. It is managed by Momenta, an operating division of AEA Technology plc, and Technology Transfer and Innovation Ltd.

Envirowise offers a range of free services including:

- Free advice from Envirowise experts through the Environment and Energy Helpline.
- A variety of publications that provide up-to-date information on waste minimisation issues, methods and successes.
- Free, on-site waste reviews from Envirowise advisors, called *Fast*Track visits, that help businesses identify and realise savings.
- Guidance on waste minimisation clubs across the UK that provide a chance for local companies to meet regularly and share best practices in waste minimisation.
- Best practice seminars and practical workshops that offer an ideal way to examine waste minimisation issues and discuss opportunities and methodologies.

For further information please contact the

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