3 Strategies for Ecodesign

3.1 Designing Ecodesign

3.1.1 Product Design Reviews – Tools and Strategies

To develop products designed for the environment is to take into account the environmental impact of certain design decisions. To help designers evaluate such decisions, numerous tools are being developed. Most often so-called *improvement tools* are used. It is clear that most tools are still in their infancy and that much research in the area is needed.

The most comprehensive design tool is *Life Cycle Assessment*, LCA. By the life cycle of a product we mean the stages through which the product passes, from the extraction and processing of its raw material, through production, marketing, transportation and use, to its end management as waste. The environmental impact of a product arises as result of the substantial consumption of resources and energy and the generation of direct or indirect pollutant emissions. It consists of the depletion of natural resources, impact on human health and degradation of environmental quality, in terms of both human and natural surroundings. Later in the book, the state of art and future expectations for Life Cycle Assessment will be discussed in some detail. In this chapter a few more simple improvement tools will be introduced. They will, however, still cover the life cycle of the product in a fairly comprehensive manner.

When reviewing design for environmental improvements, various levels can be identified (Figure 3.2). The most important are:

- Product improvement.
- Product redesign.
- Innovation in the product concept.
- System innovation.

In this Chapter

Box 3.1 Tools for Ecodesign

There are several kinds of ecodesign tools, used for different purposes. Tischner [2001] has distinguished between four such categories: 1) Analytical tools, which indicated strengths and weaknesses of a product; 2) Priority setting tools, selecting the most promising improvements possible; 3) Implementation tools, providing assistance for design, and brainstorming on ecodesign; and 4) Coordination tools, linking the ecodesign to other criteria such as cost benefit analysis, etc.

There is no consensus on what constitutes a tool. The most important feature is of course that it is useful for the designer. A few of the most important tools are briefly described below [Tischner, 2001].

LCA Life Cycle Assessment
An LCA analyses all input and output for all stages of the product life cycle. LCA is a typical analytic tool. It is complicated and time-consuming to use, but provides the most correct and quantitative picture of the environmental impact of a product. Most tools have a "life cycle approach" although they are not complete LCAs.

MET matrix
The letters MET stand for materials, energy and toxicity. A MET matrix shows the material flows, energy use and production of toxic substances for each of the stages of a product life. It is used to:

- Optimise all aspects of the material life cycle of the product, e.g. material use, re-use and recycle possibilities, reducing material and waste use.
- Reduce energy consumption during the whole life cycle, and energy content in the materials.
- Eliminate or reduce toxic (and also non-toxic) emissions.

The MET matrix is used as an analytical and strategic tool.

PRODUCT SYSTEM LEVEL

7. Optimization of end-of-life system
Reuse of product
Remanufacturing/refurbishing
Recycling of materials
Safer incineration

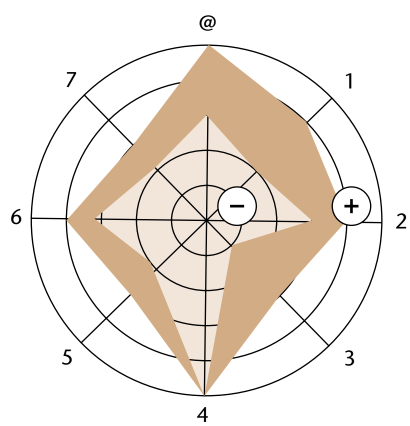
6. Optimization of initial lifetime
Reliability and durability
Easier maintenance and repair
Modular product structure
Classic design
Strong product-user relation

5. Reduction of impact during user
Lower energy consumption
Cleaner energy source
Fewer consumables needed
Cleaner consumables
No waste of energy/consumables

PRODUCT STRUCTURE LEVEL

4. Optimization of distribution system
Less/cleaner/reusable packaging
Energy-efficient transport mode
Energy-efficient logistics

@ New Concept Development*
Dematerialization
Shared use of the product
Integration of functions
Functional optimization
of product (components)



PRODUCT COMPONENT LEVEL

1. Selection of low-impact materials
Cleaner materials
Renewable materials
Lower energy content materials
Recycled materials
Recyclable materials

2. Reduction of materials usage
Reduction in weight
Reduction in (transport) volume

3. Optimization of production techniques
Alternative production techniques
Fewer production steps
Lower/cleaner energy consumption
Less production waste
Fewer/cleaner production consumables

Priorities for the new product

Existing product

Figure 3.1 The ecodesign strategy wheel. *The Ecodesign strategy wheel shows all the fields of interest in ecodesign, clustered in eight carefully chosen strategies which are pictured on the eight axes of the wheel. The strategies numbered 1-7 are mostly used in eco-redesign. The strategy indicated by the @-sign refers to new product concept developments. It is often used as a stand alone activity, leading to a completely new approach to provide a service as when e-mail replaces ordinary surface post [Hemet and Brezet, 1997; Van Hemel, C.G., 1995].*

Table 3.1 The MET matrix. *The letters MET stand for materials, energy and toxicity. A MET matrix shows the material flows, energy use and emission of toxic substances for each of the stages of a product's life. When the matrix has been filled in it gives a useful overview of the environmental impact of a product and pinpoints the most serious ones. It is used for analysis and planning of product redesign. [Te Riele, Zweers, et al., 1994].*

	M - Materials	E - Energy use	T - Waste/ Toxic emissions
Production and supply of all materials and components			
Manufacturing: in-house production			
Distribution			
Use: operation and servicing			
End-of-life system: recovery and disposal			

Materials flows strategies

Materials flows strategies (Box 2.3) covers all aspects of material flows for the product and pinpoints systematically the strategies which can be used for improvements. It is used mostly for analysis and priority setting implementation. It is developed from the Natural Step Foundation's four System Conditions [Holmberg et al., 1994]. Even though these refer to a wider agenda, as a tool for all material flows in an organisation or company, it is useful in ecodesign. The scheme refers to:

- Reducing material flows (use less material).
- Slowing down the flow (make material last longer).
- Closing the flow (that is recycling).
- Substituting the flow (taking out the toxic, non-renewable and scarce materials).

Spider web diagrams

There are several web diagrams, such as the "spider web diagrams", the "eco-compass" and the "ecodesign strategy wheel". The diagrams allow the user to assess the product against a set of environmental criteria and visualize them. The criteria typically include material use, transport use, energy use, waste produced, toxicity, and longevity. The product is given a value of 0 to 5 (sometimes 1-6 or 1-10) for each criterion, where 0 (or 1) is poor and 5 is excellent. The value is marked on the corresponding axis in the spider web. When the values for the product are connected, we have a picture, that characterises the product. The task for the eco-designer is to propose a modification of the product for which one or several of the criteria have an improved value.

Only relative values are used in the diagram, but it still gives a very vivid qualitative picture of where the improvements are needed, and how the old and new products compare. A spider web is used both for analysis and setting priorities for ecodesign.

Environmental management systems, EMS

EMS is a very valuable starting point when considering an ecodesign project. Introducing an EMS in a company includes a review and audit which should identify the weak and strong points in a company, including its production. The rationale and objectives for an ecodesign project will then be clear and the management of the company will be included and can define responsibilities and resources needed to do ecodesign. The certification schemes of ISO 14001 and EMAS also provide a valuable standardised way to set priorities, and require that the companies seek improvement wherever it is feasible including the design of its products and services.

Supply chain management (SCM)

SCM is the incorporation of environmental aspects into the decisions regarding the purchase of materials and parts for the manufacture of a product, and supplier management practices. A review of a product may tell that the major environmental impacts are caused in the supply chain rather than in the company's own manufacturing. SCM will then be a key task in ecodesign [Charter, 2001].

SCM is increasingly important as we come close to the end of a supply chain. Companies selling services typically do not themselves manufacture the products being used in the services, such as detergents for a cleaning company. The ecodesign of the service thus has to include a careful examination of the products they are using, and the choice of the best one, or even forcing the provider to improve the environmental profile of their products. Strong companies such as the large retailers may have a very strong influence on their suppliers, if they are very important customers.

Today we see that companies that are certified according to ISO standards or EMAS ask the suppliers to get certified as well, and may exchange suppliers if they do not comply.

SCM also includes a careful examination of how and from where the suppliers deliver the products. There may be a choice of finding a supplier that is situated closer to reduce transport, or one that is using a better mode of transport.

The first two levels indicate small stepwise improvements of an existing product. The latter two take the function of a specific product as starting point and try to provide that function in a more environmentally-friendly fashion. In product redesign only the former two levels are approached in actuality. To realise a satisfactory global reduction of environmental impact, our attention however must be shifted to the latter two categories. In this chapter eco-redesign, that is levels 1 and 2, will be the main concern. The third level will be briefly discussed below under the heading New Concept Development. The fourth – system – level will be brought up in Chapter 12. A further description of different design levels with exemplifications is given in Table 3.2.

3.1.2 Ecodesign Tools

There are several different tools to use when working with ecodesign. The tools have been developed by various companies or research groups, and used as standard strategies in product development, just as much for business as for environmental reasons. The tools typically address issues of :

- Dematerialisation (decreasing weight and volume).
- Substitution (replacing toxic components, and non-renewables).
- Reducing energy use (both in production and during use).
- Reducing transport needs (e.g finding resources from neighbouring areas).
- Increasing life span of product (e.g increasing repairability).
- Reducing waste generation (e.g. by increasing recycling).

A commonly used tool is the *MET matrix*, where the letters refer to *reduced materials, energy and toxicity*. These three are key words in for example the Brundtland report, which asks for improved effectiveness, efficiency and life-time of products. Another important and commonly used group of tools are the *spider web diagrams* addressing the environmental requirements for a product. The spider web diagrams allow the designer to implement ecodesign in strategic steps. Each one of these is visualized in the diagram and the improvements achievable with a new design can be seen directly. Several of the tools are reviewed in Box 3.1.

Optimisation of the product requires that functional, economic and environmental requirements are all included and balanced. Other tools are used to look at the economic and functional aspects of a re-design project (See Chapter 14). Quite often, however, the result of an ecodesign project is in itself also beneficial for these aspects. One example is the Sony TV, which in the early 1990s was rated badly from an environmental point of view. Not to lose market shares, the management of the company decided to improve. The re-designed TV had eliminated hazardous material, had 52% less plastic, less material over all and was easily disassembled (with only nine screws) to allow 99% recycling. As an additional benefit, it turned out that the new product was 30% cheaper to produce, and could be assembled much faster! Both economy and functionality was improved through the ecodesign process [Design for Environment Guide, 2003].

3.1.3 The Ecodesign Strategy Wheel

The *Ecodesign strategy wheel* (Figure 3.1) [Hemel and Brezet, 1997; Van Hemel, C.G. 1995], the perhaps most widely used spider web diagram, is a very useful and comprehensive way of classifying the different strategies. It was developed mainly at Delft University in the Netherlands. It was the basis of a widely used manual published by UNEP [1997], commonly called the *Promise Manual* (full name is *Ecodesign "A promising Approach – to sustainable production and consump-*

Table 3.2 Levels of eco-redesign of products. *The table specifies the levels at which the redesign can be made from substitution of resources to the concept level [Månsson, 1993; Holmberg et al., 1994].*

Level of substitution	Example
1. The raw material level	The same material may be obtained from different raw materials with different environmental characteristics, e.g., hydrocarbons from biota or fossil fuels.
2. The material level	Aluminium can substitute for copper in electrical power transmission.
3. The component level	One type of battery may have better properties than one currently in use.
4. The subsystem level	Electric motors may at one time replace internal combustion engines for cars in local traffic.
5. The system level	Private cars may be largely replaced by trains for medium – and long-distance travelling.
6. The strategic level	Different strategies can lead to the same goal. If the goal is "clean" environment, then there can be a shift in scientific strategy from environmental pathology to societal prophylaxis.
7. The value level	Cultural and individual values decide what strategy to choose. Moreover, if people want sustainable development, this will lead to consequences at all other levels.

tion"). The strategy wheel is a conceptual model, which shows all the fields of interest in ecodesign, clustered in eight carefully chosen strategies which are pictured on the eight axes of the wheel. These are:

Product component level.
1. Choosing low impact materials.
2. Reduction of material flows.

Product structure level.
3. Design for environmentally friendly (cleaner) production.
4. Design for reducing transport.
5. Design for green use.

Product system level.
6. Design for a longer life.
7. End-of-life design.

Strategies numbered 1-7 in the wheel concern the improvement of an existing product, often called eco-redesign. The 8th strategy, symbolised by the @-sign, refers to the so-called New Concept Development. A new concept development is not just a better product but a new way to provide the service that the product is there for. The sign is meant to remind us that the Internet is a very powerful alternative to older means of communicating, especially sending by surface mail. It also makes available music, messages and pictures in a new way. Even if one should not forget that also implementation and use of Internet has its environmental impact that needs to be evaluated, it still carries the idea of new strategic thinking.

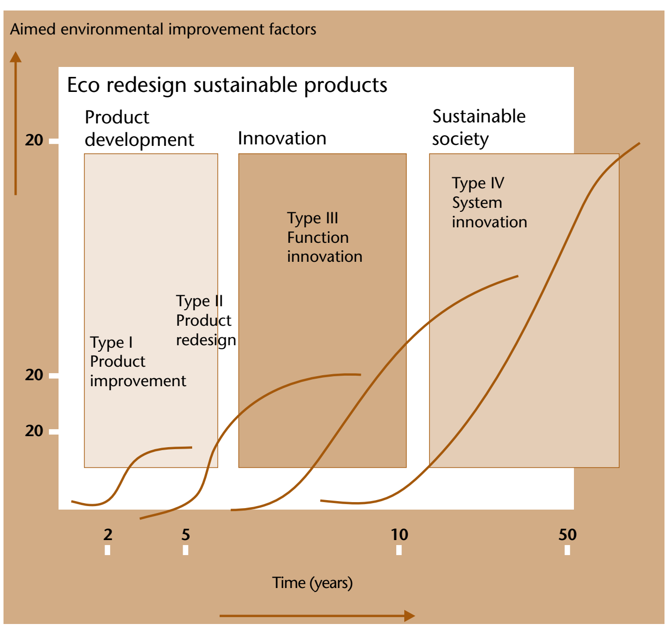


Figure 3.2 Four types of environmentally friendly product service development *[Korbijn, 1999].*

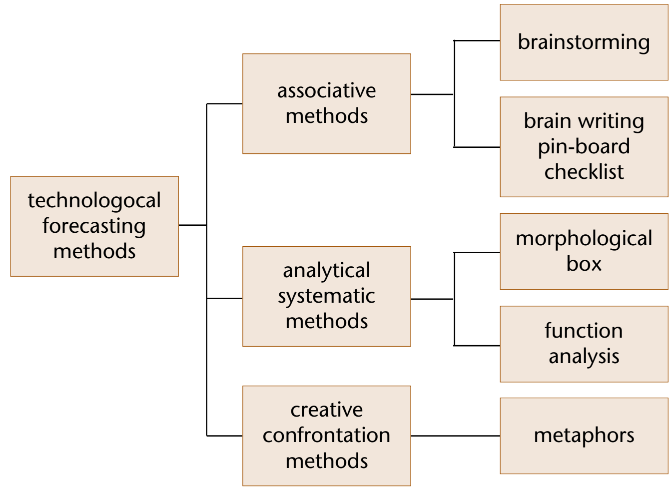


Figure 3.3 Overview of creativity techniques. *The figure summarizes a number of techniques used to stimulate creativity in order to come up with new product concepts or developments. The techniques are further described in the manual published by UNEP called "Ecodesign – A promising approach" often referred to as the Promise Manual which in turn is based on the ecodesign strategy wheel [UNEP, 1997].*

One of the best ways to develop and describe your ecodesign strategy is to complete an ecodesign strategy wheel. In the rest of this chapter we will address each item of the wheel in turn. But first a few general comments, mainly based on the *Design for Environment (DfE) Guide* of the Industrial Research Assistance Program of the National Research Council of Canada, in turn based on the original promise manual of the Technical University of Delft.

The strategies in the wheel are numbered according to the life cycle of the product. But this is not necessarily the best sequence when implementing re-design strategies. It will differ between products, between companies and the situation, and no one is "always right". For example when re-designing a photocopier the first concern was to reduce energy consumption during use (strategy 5, reduce impact during use) as it would be very important for the function of the machine. How to select material (strategy 1) or improve recyclability (strategy 7) could wait till the end, since it would not influence function in the same way. However when looking at a package, the material selection (strategy 1) would be the first strategy to deal with, for obvious reasons.

The wheel can be used in many ways and for several purposes. First of all it is a visual representation of the environmental profile of the existing product; it can provoke and inspire improvement options; it is helping you to compare and balance different improvement strategies; it will provide a useful visual comparison between the old and the new product, and for that reason a useful means to communicate your ideas to others, both within an organisation, a company, and to the outside world.

You may also go through each of the stages in product's life cycle and apply all the strategies to each one of them. Thus for resource use, that is the supply chain, all eight strategies can be considered, and so on for all other stages. This will make the design process more challenging, and may in the end lead to a new way to satisfy the customer's demand of the service that the product actually is providing for. It is far more difficult to achieve a good "new concept" than just make a redesign of a product addressing one or a few of the strategies in the wheel.

An outline of a design process is given in Box 3.2

Box 3.2 Sequencing an Ecodesign Strategy

Step 1 An idea for the new product
The starting point may be brain storming for example inspired by the ecodesign strategy wheel. A few key issues for your product will result, for example, how to reduce energy spending during the use phase, how to increase recycling of components, how to manage with less or no packaging. Some of the issues are looked into further through feasibility studies. The results of step 1 should be a short report, a so-called design brief.

Step 2 A conceptual design
Next is to look into one or a few of the ideas from step 1 and specify principles or techniques to use for a new design. Referring to the three examples above, these should include an exact description of what principle or technique to use to save energy (insulation, control, new energy source etc), specifying what material to use in some parts to increase recycling, and thirdly how to develop minimal packaging. Step 2 should lead to a report with a short list of specifications for several concepts. One or several of these are then chosen for further work.

Step 3 A preliminary design
The third step constitutes the design of the alternatives chosen from step 2. All details of the product should now be specified, including function, choice of materials and, if possible, a quantitative estimate of the environmental improvements of the new design. Step 3 should end with a preliminary design.

Step 4 A detailed design
The detailed design should include all data needed for the manufacturing and supply chain of the new product. All materials should be specified. The assembly and disassembly, as well as the repair and maintenance of the product need to be described. The packaging and delivery of the product and finally the take back or recycling at the end-of-life of the product is described.

Source: National Research Council of Canada, DfE Guide.

3.1.4 Product Design as a Creative Process

Ecodesign makes heavy demands on individual creativity. Some tools used are creativity-stimulating techniques. They attempt to find best answers to the question "How can we conduct a structural search for ideas?" Figure 3.3 gives an overview of the most used creativity techniques which can also be of help in searching for environmental improvements. (A more detailed description on brainstorming is available as a workshop on the accompanying CD.)

3.2. New Concept Development

3.2.1 Dematerialisation

As mentioned the @-symbol in the ecodesign strategy wheel refers to the strategy that the need for the product may be met in a new way, that is to develop a new concept. A thorough analysis of the need that the product fulfils is necessary to find new concepts. It is very often that this analysis leads to an increased use of shared services, or in general that a service is provided rather than a product. This strategy may be divided into three approaches – dematerialisation, increased shared use and service provision.

Dematerialisation is to replace the physical product with a non-physical one, to reduce the demand of the company for physical products as well as the dependency of the end user on physical products. Obviously such a strategy will reduce costs of material, transport, and energy. Dematerialisation may be that the product itself is becoming smaller and lighter, that the product is replaced with a non-material substitute (as the @-symbol indicates) or that the infrastructure needed is reduced or eliminated. Examples are easy to find (and doing so is a good exercise). Information and communication technologies provide many. Computers are getting smaller and use less electricity. As e-mails substitute for sending surface post the need for a number of physical structures are eliminated. The use of mobile telephones instead of classical ones, leads to a new and completely different and slimmer infrastructure. It is interesting to see how developing countries repeatedly frog-jump several technical generations as they introduce slimmer (and cheaper) technologies.

3.2.2 Shared Use of Products

When many individuals make common use of a product without actually owning it the product is normally used more efficiently. Typical examples are common laundry machines, tools for construction or gardening, or equipment for offices such as copiers, and fax machines. The product often becomes the property of an organisation or company, which is managing the shared use. A new organisation may be needed and created.

From the customers' point of view, as products are not used often, it may be advantageous to pay for the individual use rather than the product itself. For the company which owns the product this is a new business opportunity. The company normally can provide the necessary maintenance, technical support etc. better since they know their product in detail, and may even develop the product to their advantage.

The arrangements may take several forms. Companies which lease equipment, for example, for building or gardening or for offices, are common. Associations of house owners sharing equipment are also common. Associations for car pooling are becoming more common, often composed of the owners of one or a few cars. Shared ownership and use of summerhouses, boats, etc is also seen.

3.2.3 Service Instead of Products

Sometimes companies find that they can increase profit and add value to a product when selling the service that the product is needed for rather than the product itself. When this happens the company assumes responsibility for maintenance, repair as well as end-of-life, such as recycling. The customer which then buys a service does not have to worry about these things.

One example is Nortel (see *Strategies: Increase shared use* in the Design for Environment Guide) who were buying detergents for their electronic manufacturing to clean their products. At one point this arrangement was changed so that instead the cleaning service was bought from the supplier of the detergent. It turned out that the supplier used the detergent much more efficiently and the whole operation was considerably cheaper. The two – customer and provider – agreed on sharing the benefit. For Nortel this change meant less chemicals and better economy.

Rental services often provide a piece of equipment that is complex or expensive. It may be costly for those in need of the equipment to own and maintain it. The concept of providing a service instead of a product, which today is becoming increasingly common, is making sense. Some truck manufacturers lease rather than sell the trucks to the company which needs transport. They thereby become responsible for maintenance and repair of the car as well as the efficient use of fuel. All these make it more likely that the truck itself will have a longer life, and be more efficiently used and consume less fuel, as it is in the interest of the truck producer. On the other hand, if the company are selling the trucks themselves, it is rather in their interest to sell more trucks.

3.3 Choosing Low Impact Materials (Step 1)

The first step in the ecodesign strategy wheel is focused on the impact of materials. It is divided by the different properties of the materials. One should thus choose:

- Non-toxic materials.
- Renewable materials.
- Low energy content materials.
- Recycled materials (from recycling).
- Recyclable materials (to recycling).

3.3.1 Toxicity

Some materials and additives are best avoided since they are toxic or cause toxic emissions during their production, use or when incinerated or dumped.

The most hazardous chemicals are those which combine persistence (long-term survival in the environment) with biological availability and reactivity. The majority of such chemicals belong to three main groups of chemical compounds [Rydén et al., 2003].

Polyaromatic hydrocarbons (PAH) i.e. molecules composed of a number of aromatic rings.

Metals, especially heavy metals, and their organic compounds, especially mercury, cadmium and lead.

Halogenated hydrocarbons, organic substances with one or more hydrogen atoms replaced by chlorine (or bromine or fluorine, i.e. by halogens).

These materials are found not so often in the main material of a product (with some exception, e.g. lead batteries) but quite often in additives such as:

- Dyes (colorants).
- Heat or UV stabilizers.
- Fire retardants.
- Softening agents.
- Fillers.
- Expanding agents.
- Anti-oxidants.

Some dyes and fire-retardants are especially hazardous. In many countries the use of the most toxic materials is prohibited by law. It is evident that the use of material with the lowest toxicity should be chosen in the eco(re)design process.

The list of potentially toxic substances is virtually endless, and for many substances the toxic effect is unknown or not sufficiently documented. Toxic substances may be classified according to their mode of action [Walker et al., 2001] as:

Genotoxic – causing DNA damage. Genotoxic effects are detrimental for reproduction; they may damage the new individual as well as cause cancer through transformation of somatic cells.

Neurotoxic – affecting the nervous system.

Immunotoxic – interfering with the immune system.

Metabolic disruptors – e.g. uncouplers of oxidative phosphorylation or inhibitors of the electron transport chain.

Osmotic disruptor – disturbing osmoregulation.

Hormone disruptors – disturbing hormone regulation.

Providing evidence of a causal link between a chemical and an effect, such as tumour incidence, is a complex task and needs the consideration of both experimental results and epidemiological studies. The International Agency for Research on Cancer (IARC) is one scientific body performing such qualitative risk assessments on substances according to the evidence available on human or animal carcinogenicity. A number of other systems are used to estimate toxicity. The chemicals inspectorate of the country is normally responsible for providing information on the toxicity of various materials.

Heavy metals should be given special attention. The most dangerous are mercury and lead. Mercury is slowly becoming outlawed in several countries. Lead in leaded gasoline was particularly bad since it was part of the car emissions and inhaled on the streets. In Western Europe and North America unleaded gasoline is now used. Another concern is cadmium, which is now increasing in the environment. In many countries cadmium is outlawed in some products, e.g. dyes.

It is difficult to judge which is worse: a more dangerous but uncommon substance that causes a serious effect on a limited number of individuals or a very common substance that cause moderate effects on a large number of people. The Commission on Environmental Toxicology of the Committee of Ecology in the Polish Academy of Science prepared a list of the most deleterious substances to people. The list is based on analyses of such criteria as the emission level, toxicity, the area of target population, bioaccumulation, biomagnification, and effects on the physical and chemical environment. The higher the number given in the list, the greater the risk of health alterations from pollutants.

The result was the following: Sulphur dioxide (114), Suspended dust matter (108), Polycyclic aromatic hydrocarbons, PAH (88), Nitrogen oxides (83), Fluorides (72), Lead (52), Cadmium (42), Nitrate fertilisers (42), Carbon monoxide (29) and Pesticides (28).

3.3.2 Risk Management

Sometimes it may be necessary to include a hazardous substance in a product. It is then necessary to be aware of the rules applying to the management of such chemicals. All OECD countries, including the EU countries, have a system for listing toxic chemicals and a methodology for assessing the risk of chemicals. The assessment addresses both human toxicity and ecotoxicity, that is, toxicity to the environment and ecosystems.

The OECD protocol of 1989 includes the following steps: On the basis of collected data the *effects* on human health are identified and quantified. The *exposure* of humans resulting from release, transport and fate of a chemical in the environment is then assessed. The next step is *hazard assessment*, i.e. determination of the probable type and magnitude of toxic effects from the released compound. Finally *risk assessment*, which includes the estimation of the probability of the relevant effects occurring from the exposure to a chemical [Van Leeuwen and Hermens, 1995] is done.

The current EU Directives on Risk Assessment are based on Regulation EC 1488/94 (Box 3.3). In 2005 a new, comprehensive chemicals policy suggested by the Commission, the so-called REACH (Registration, Evaluation and Authorisation of Chemicals) was introduced. It will lead to a comprehensive scheme for management of all chemicals in the Union. Its im-

Table 3.3 Toxicity of heavy metals to humans. *The data are specified for different diseases caused by the heavy metals and the most sensitive age groups [Eco-indicator 99, 1999].*

Metal	Type of disease/ function/organ	Sensitive age
Arsenic	Cardiovascular	Elderly
Aluminium	Nervous systems	Foetus, Children
	Osteoporosis	Elderly
Cadmium	Cardiovascular	Elderly
	Osteoporosis	Elderly
Chromium	Nervous systems	Foetus, Children
Cobalt	Osteoporosis	Elderly
Lead	Cardiovascular	Elderly
	Reproduction	Foetus, Young
	Nervous systems	Foetus, Children
	Osteoporosis	Elderly
Manganese	Nervous systems	Foetus, Children
Mercury	Reproduction	Foetus, Young
Nickel	Allergy and Hypersensitivity	Children
Selenium	Osteoporosis	Elderly

Box 3.3 Risk Management

All chemicals that are introduced to the market need today to be *registered and accepted* by the appropriate authorities, normally the Environmental Protection Agency or Chemicals Inspectorate of the country. The registration requires that basic data on the substance are provided. Data are used to assess the risk to human health and the environmental hazard of the compound.

Existing substances also need to be registered. In the EU existing substances are defined as those which were on the market prior to 1981 and which are listed in the EINECS database according to EC regulation 793/93 on evaluation and control of the environmental risks of existing substances. The EINECS database includes more than 100,000 substances. In the regulation the data gathering is the responsibility of the chemical producer or importer. For all products, sold or imported in quantities of 1 to 1,000 tonnes annually, the authorities will set priorities based on data on exposure in the environment and to people – as consumers and workers – and the long-term effects (the so-called IPS method).

Each substance has to undergo risk assessment. The risk assessment is carried out according to Risk Assessment Regulation EC 1488/94. The basic steps are hazard identification, exposure assessment, effects assessment, and risk characterisation.

Based on the results from the risk assessment a risk management strategy is developed. The basic steps are risk classification, risk-benefit analysis, risk reduction, and monitoring.

Risk classification is not only based on scientific considerations but also on what is considered to be an acceptable risk. Acceptability varies with time and place. What was acceptable in the past might not be so any longer, and risk acceptance varies between places and countries. One normally defines two risk levels, the upper risk level, maximum permissible risk, and the lower level, the negligible risk. The two limits create three zones: a black (high risk) zone, a grey (medium risk) zone, and a white (low risk) zone. An actual risk in the black zone is not accepted and legal action is taken, while no such action is needed in the white zone. Often one defines the low risk zone as 1% of the upper risk zone. Then there is a margin for possible underestimations due to e.g. additivity and synergistic effects between chemicals, and in general uncertainties and errors.

When the risk classification is done, there is the difficult task of *weighting the costs and benefits* of different measures of risk reduction. Before risk reduction one needs to know the technical possibilities, costs, the social and cultural factors, e.g. does it lead to unemployment, and the legislative possibilities? The cost-benefit analysis is carried out using estimates, most often in monetary terms, of the benefits for human health in terms of lives saved, lifetime extended, etc. Environmental risks are much more difficult to quantify, although costs for abatement or cleaning up can be used. From the estimates of cost one then decides on risk reduction measures.

Risk reduction deals with measures to protect people or the environment against identified risks. There are in general three approaches to risk reduction:

1. Classification and labelling of chemicals, to communicate the risk, according to an established system of symbols and regulations.
2. The ALARA (as low as reasonably achievable) approach which places the responsibility for lowering the risk on the operator, manufacturer or user.
3. Safety standards. These are fixed upper limits of exposure to certain chemicals as established in regulations. Examples of standards are threshold limit values, TLV, acceptable daily intake, ADI, and environmental quality standards.

Finally, risk management includes *monitoring and follow-up*. This is done to assure that the measures taken are completed and formulated standards relevant. Monitoring also serves the purpose of control, alarm, long-term trend study, and research to further identify the mechanisms of emissions, distribution, toxicity, etc.

Source: Based on Van Leeuwen and Hermens, 1995.

Figure 3.4 Labels for chemical management. *The labels are used to communicate the risks connected with the chemicals. The labels from top left indicate flammable, poisonous, corrosive, ecotoxic, allergic, explosive and oxidising. For each category there are strict rules for classification e.g. in terms of* LD^{50} *on rats, or flame point, etc. The Chemicals Inspectorate in each country maintains databases where the regulations for storing, handling, and disposing of each chemical can be found.*

plementation is expected to last about ten years, that is, up to about 2015 (see Internet Resources).

If a chemical is classified as toxic or otherwise hazardous, e.g. if a biocide is included in a product, a proper management scheme has to go along with it. This includes information, especially proper labelling, and instructions for risk reduction (Box 3.3).

3.3.3 Renewable Materials

Materials should be avoided if they are from sources that are not replenished naturally, or take a long time to do so, implying that the source can be become exhausted in time. Examples are fossil fuels, tropical hardwoods, and metals such as copper, tin, zinc and platinum.

Some scientists regard depletion as a minor environmental problem since the materials involved eventually become very expensive, with the result that they will be recycled and alternative materials will be developed. However the rule is that more often the dissemination of a material from a deposit, to which it is not returned, leads to accumulation, and it becomes harmful in the environment long before the source is exhausted.

Non-renewable materials are used extensively. Oil is the basic raw material in petrochemical processes which dominates chemical industry. The replacement of oil-based chemistry is slowly introduced, under the name of "green chemistry". Basic chemicals are then made from biomass, e.g. ethanol from corn or wheat, and methanol from wood. These can be further processed to plastics and other materials. Vegetable oil produced from e.g. rape seeds are used in some processes. However 90-95% of oil products are incinerated in energy production and the replacement of fossil in the energy sector is thus the most urgent.

Non-ferrous metals are also used in large scale although they are non-renewable. Production of virgin metals is connected to considerable environmental impacts compared to use of recycled metal, or replacement options. For example the replacement of copper by optical fibres in communication systems has clear environmental benefits, as have the use of recycled metals, even if copper is not as such close to depletion or very toxic.

Recycling of metals is thus an environmentally important undertaking. When it comes to toxic metals such as lead, it is essential. Recycling can be made very efficient, more than 99% for e.g. lead, with carefully designed systems [Karlsson, 1997].

The issue of non-renewable materials is further discussed in Chapter 2.

Hints for step 1
Find Low Impact Material

Non-toxic material

1. Do not use materials or additives that are toxic. These include among others:
   - PCBs: polychlorinated biphenyls (prohibited in all countries).
   - PCTs: polychlorinated terphenyls.
   - Lead (in PVC, electronics, dyes and batteries).
   - Cadmium (in dyes and batteries).
   - Mercury (in thermometers, switches, fluorescent tubes).

   PCB and PCT are on the black list of substances banned in the 2002 Stockholm Convention. The others are on the grey list. They can be used with required precautions.
   Avoid the use of summer-smog-causing hydrocarbons.
2. Find alternatives for surface treatment techniques, such as hot-dip galvanization, electrolytic zinc plating and electrolytic chromium plating.
3. Find alternatives to non-ferrous metals such as copper, zinc, brass, chromium and nickel because of the harmful emissions that occur during their production.

Energy efficient material

1. Avoid energy-intensive materials such as aluminium in products with a short lifetime.
2. Find alternatives for exhaustible materials.
3. Avoid raw materials produced from intensive agriculture.

Recycled and recyclable materials

1. Use recycled materials wherever possible.
2. Use recycled plastics for the inner parts of products which have only a supportive function and do not require a high mechanical, hygienic or tolerance quality.
3. When hygiene is important (as in coffee cups and some packaging) a laminate can be applied, the centre of which is made from recycled plastic, covered with, or surrounded by, virgin plastic.
4. Make use of the unique features (such as variations in colour and texture) of recycled materials in the design process.
5. Preferably use recyclable materials for which a market already exists.
6. Avoid the use of polluting elements such as stickers which interfere with recycling.

3.3.4 Low Energy Content Materials

Some materials, whose extraction and production is very energy intensive, have higher energy content than others. Use of these materials is justified only if they lead to other, positive environmental features of practical use in the product. For instance, aluminium has high energy content. It is produced in a system which requires large amounts of electricity. Still it may be appropriate to use it in a product which is often transported and for which there is a recycling system in place. This is because aluminium is a light material and most suitable for recycling.

3.3.5 Recycled or Recyclable Materials

Recycled materials are materials that have been used in products before. If suitable, use these materials again and again so that the materials and the energy invested to make them are not lost. An example is copper. Recycled copper is about 50 times less material intensive than virgin metal, that is, the ecological rucksack of virgin copper is about 50 times larger than for recycled copper. Also recycled iron (6 times) and recycled aluminium is much less resource intensive than virgin metal [Schmidt-Bleek, 1994]. The use of recycled materials corresponds to "closing the materials flows" (Box 2.3 *Materials Management Strategies for Improved Material Flows*).

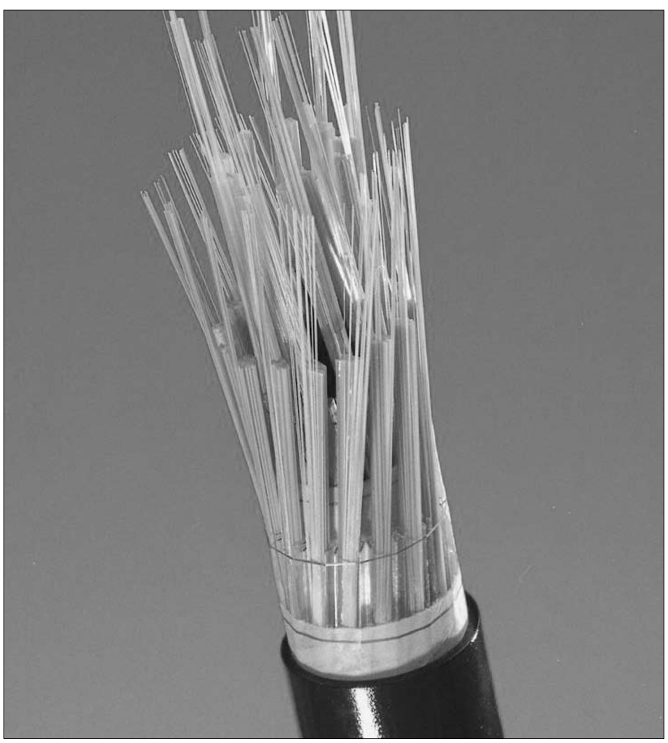


Figure 3.5 Material substitution and dematerialisation. *Exchanging copper wires for optical fibres is an excellent example of substituting a more (copper) to a less (glass) resource intensive material.*

3.4 Reducing Material Flows (Step 2)

3.4.1 Dematerialisation

The most direct way to reduce material flows is to dematerialise the product. There are several ways to achieve this.

Make the product smaller, and less material is used. Computers, now based on miniaturized electronic components, may provide the most dramatic example, when compared over the last 20 or so years.

Increasing the rigidity through construction techniques, such as reinforcement ribs rather than over-dimensioning the product, will lead to less material use, as will increasing its strength, e.g. by replacing a metal with a stronger alloy.

Multi-functional use of products also leads to dematerialisation. For example, a roof-mounted solar collector can also function as roofing.

Reducing the weight and size of a product is good not only directly for decreasing materials and resource use. There are also indirect effects.

Dematerialisation is very importantly related to the transport of the raw materials from supplier to producer as well as the final product to the retailer and or customer. Thus the space required for transport and storage is decreased by decreasing the product weight and total volume, as is the energy required for transport. This obviously improves the economy of production.

Another example: When using wood rather than cement for house elements, some 75 % of weight reduction was achieved. This decreased considerably the environmental effects of truck transport, as well as wear on roads [Karlsson, 1997].

Finally it may be said that quality is better expressed through good design rather than over-dimensioning the product.

Hints for Step 2
Dematerialisation

1. Aim for rigidity through construction such as reinforcement ribs rather than "over-dimensioning" the product.
2. Aim to express quality through good design rather than over-dimensioning the product.
3. Aim at reducing the amount of space required for transport and storage by decreasing the product's size and total volume.
4. Make the product collapsible and/or suitable for nesting.
5. Consider transporting the product in loose components that can be nested, leaving the final assembly up to a third party or even the end user.

3.4.2 Avoid Highly Resource-intensive Materials

Some materials are very resource intensive, and thus their use will lead to high material flows, and have a large environmental impact. There are many examples of such material, especially those with large energy intensity, large materials turnover, and where much transport is required.

By way of illustration, the United Kingdom currently uses approximately 10 tonnes of raw material to make one tonne of product. The nine tonnes that are not part of the product but still connected to the extraction of the useful material is called the *ecological rucksack* [Schmidt-Bleek, 1994]. They are merely a necessary part of extraction or are more or less unavoidable by-flows. Overburden has to be moved to obtain the useful materials and ores exposed to the applied extraction methods. Furthermore, high-value metals like copper are extracted from metal ores that contain only small amounts of metals. (The grade of copper ore can be as low as about 0.3%.) The non-metal remainder is discarded in the refining process and is part of the rucksack.

The relation between useful material and the rucksack varies considerably with different materials. For iron this factor is 1:6, but for copper it is normally 1:800. For those resources where the rucksack is large, the use of recycled material is an environmentally very favourable alternative [Schmidt-Bleek, 1994].

3.5 Design for Production (Step 3)

3.5.1 Decreasing Resource and Energy Flows

Good design also has to consider the production phase. Production techniques should have a low environmental impact: they should minimize the use of auxiliary (especially hazardous) materials and energy, lead to only limited losses of raw material and generate as little waste as possible.

Both extraction of raw materials and production of the product require energy. Substantial environmental gains can be achieved if energy use is minimised and the right kind of energy is used in both processes. Some extraction processes are energy intensive, e.g. for the production of aluminium.

There are also substantial business gains in reducing energy use. It reduces costs, especially if energy taxes are high. It reduces dependencies on energy, which makes production less sensitive to problems of energy deliveries, e.g. during cold winter days. Finally e.g. if fossil fuel is used for boilers etc, emission are reduced together with the volume of fuel.

The energy that is used should preferably come from renewable sources, such as biomass. Other renewable sources are wind power and hydropower. Today waste incineration is increasingly used. Finally solar energy, either as solar heating or as photovoltaic electricity, is rapidly becoming more important. If fossil fuel are used, natural gas is better than oil, and oil is better than coal, and it is better to choose low-sulphur grades fuels. To improve the energy situation in society taxation is used as economic incentives to make economic and environmental concerns coincide.

Cleaner production also (see below) aims to reduce energy consumption in existing production processes. It is important to motivate the production department of a company and suppliers to make their production more energy efficient. Encourage them to make use of renewable energy sources.

3.5.2 Cleaner Production Techniques

It is possible to review (audit) the production of a product to find opportunities for reduction of materials use, reducing the use of harmful materials, and reducing waste. This strategy is called *cleaner production* through process improvements. The environmental improvement of production processes is one of the components of the environmental management systems. The production department and suppliers work to improve the efficiency with which operational materials are used during production, for example, by good housekeeping, closed production systems and in-house recycling.

The cleaner production techniques include:

Using *fewer harmful auxiliary substances* or additives (for example, by replacing CFCs in the degreasing process and chlorinated bleaching agents); reducing the production con-

Figure 3.6 *Electric powered cars, La Rochelle France. Photo: Barbara Kozlowska.*

Hints for step 3
Alternative Production Techniques

Cleaner techniques
1. Preferably choose clean production techniques that require fewer harmful auxiliary substances or additives. For example, replace CFCs and other chlorinated bleaching agents in the degreasing process.
2. Select production techniques which generate low emissions, such as bending instead of welding, and joining instead of soldering.
3. Choose processes which make the most efficient use of materials, such as powder coating instead of spray painting.

Fewer production steps
1. Aim to use the lowest possible number of production techniques.
2. Combine constituent functions in one component so that fewer production processes are required.
3. Preferably use materials that do not require additional surface treatment.

Lower/cleaner energy consumption
1. Aim to reduce energy consumption in existing production processes.
2. Motivate the production department and suppliers to make their production more energy efficient.
3. Encourage them to make use of renewable energy sources such as natural gas, low-sulphur coal, wind energy, water power and solar energy.

Less production of waste
1. Design the product to minimize material waste, especially in processes such as sawing, turning, milling, pressing and punching.
2. Reduce waste and the percentage of rejects during production and in the supply chain.
3. Recycle production residues within the company.

Fewer/cleaner production consumables
1. Reduce the production consumables required, for example, by designing the product so that during cutting, waste is restricted to specific areas and cleaning is reduced.
2. Improve the efficiency with which operational materials are used during production, for example, by good housekeeping, closed production systems and in-house recycling.

sumables required, for example, by designing the product so that during cutting, waste is restricted to specific areas and cleaning is reduced.

Using *techniques with low emissions*, such as bending instead of welding, joining instead of soldering.

Choosing processes which make the most *efficient use of materials*, such as powder coating instead of spray painting.

Preferably using materials that *do not require additional surface treatment*.

Cleaner production aims to reduce the number of production steps, by combining constituent functions in one component so that fewer production processes are required.

Cleaner production also aims to design the product to minimize material waste in processes such as sawing, turning, milling, pressing and punching. Here production residues should preferably be recycled within the process, or at least the factory.

Finally waste should be minimised, e.g. by reducing the percentage of rejects during production.

The strategy of cleaner production through process improvements is an approach with which industry is becoming more and more familiar. The environmental improvement of production processes is one of the components of the environmental management systems (EMS) which are now being used by industry, and which can be certified through the European Union Eco-management and Audit scheme EMAS, and the ISO 14001 standard.

3.6 Design for Distribution (Step 4)

3.6.1 Distribution Systems

The strategy of environmentally efficient distribution is there to ensure that the product is transported from the factory to the retailer and user in the most efficient manner. This relates to the product itself as well as the packaging, the mode of transport, and the logistics. If a project also includes a detailed analysis of packaging, the packaging should be regarded as a product in itself, with its own life cycle.

The most obvious possibility is to reduce transport as such by working with local suppliers in order to avoid long-distance transport.

The choice of transport mode is important. Ecodesign includes the avoidance of environmentally harmful forms of transport. Transport by air is the least environmentally favourable, road transport by truck, comes next, and transport by container ship or train is most preferable.

Efficient loading of the chosen mode of transport, as well as efficient distribution logistics, can also reduce environmental impact. Some rules are to introduce efficient forms of distribution, for example, the distribution of larger amounts of different goods simultaneously; and to use standardized transport packaging and bulk packaging (Euro-pallets and standard package module dimensions).

3.6.2 Estimating the Environmental Impact of Transport

Transport processes include the impact of emissions caused by the extraction and production of fuel and by the generation of energy from fuel during transport. The unit which you have to count (in the Eco-indicator method) is the transport of one tonne (1000 kg) of goods over 1 km (1 tonne x km). A different unit is used for bulk road transport. In the Eco-indicator three forms of transport are recognised:

- *Road transport*. In addition to transport for which the mass is the critical factor (tonne x km), an indicator has also been determined for those cases where the volume is the determining factor (m^3 x km).
- *Rail transport*. This is based on the average European ratio of diesel to electric traction and an average load level.
- *Air transport* for different types of cargo planes.

A loading efficiency for European average conditions is assumed. Account is also taken of a possible empty return journey. Capital goods, like the production of trucks and road or rail infrastructure, and the handling of cargo planes on airports, are included as they are not negligible.

3.6.3 Packaging Systems

An important component of transport is the packaging of the product. Here considerable environmental gains can be made.

Some strategies can be considered even when designing the product itself. The space required for transport and storage can be minimised by decreasing the product's size and total volume. The product can also be collapsible and/or suitable for nesting, to reduce transport volume. It is also possible to consider transporting the product in loose components which can be nested, leaving the final assembly up to a third party or even the end user.

The principle of less/cleaner/reusable packaging intends to prevent waste and emissions. The less packaging required, the greater is the saving on materials used and the energy needed for transport. Some rules are:

If all or some of the packaging serves to give the product a certain appeal, use an *attractive but lean design* to achieve the same effect.

Hints for step 4
Distribution and Transport

Less/cleaner/reusable packaging
This principle involves preventing waste and emissions. The less packaging required, the greater is the saving on materials used and the energy needed for transport.

1. If all or some of the packaging serves to give the product a certain appeal, use an attractive but lean design to achieve the same effect.
2. For transport and bulk packaging give consideration to reusable packaging in combination with a monetary deposit or return system.
3. Use appropriate materials for the kind of packaging, for example, avoid the use of PVC and aluminium in non-returnable packaging.
4. Use minimum volumes and weights of packaging.
5. Make sure the packaging is appropriate for the reduced volume, collapsibility and nesting of products.

Energy-efficient transport mode
The environmental impact of transport by air is far greater than transport by sea. This affects the choice of transport mode.

1. Avoid environmentally harmful forms of transport.
2. Transport by container ship or train is preferable to transport by lorry.
3. Transport by air should be prevented where possible.

Energy-efficient logistics
Efficient loading of the chosen mode of transport, as well as efficient distribution logistics, can also reduce environmental impact.

1. Work preferably with local suppliers in order to avoid long-distance transport.
2. Introduce efficient form of distribution, for example; the distribution of larger amounts of different goods simultaneously.
3. Use standardized transport packaging and bulk packaging (Euro-pallets and standard package module dimensions).

Table 3.4
Example of environmental purchasing criteria for the retail trade.

Packaging
Restriction on size reduction of material usage
Use mono-materials improve initial use
Limit variation in shape less production pollution
Reduce printing less production pollution
Reused materials
Chlorine-free bleached

Use *appropriate materials* for the kind of packaging, for example; avoid the use of PVC and aluminium in non-returnable packaging.

Use *minimum volumes* and weights of packaging.

For transport and bulk packaging give consideration to reusable packaging in combination with a monetary deposit or return system. Recycling processes cause an environmental load as all other processes do; however recycling processes also result in useful products. These products can be interpreted as an environmental gain, as they avoid production of materials elsewhere.

3.7 Design for "Green" Use (Step 5)

3.7.1 Reducing Energy Consumption During Use

The most important issues during use are energy and waste. First energy: design the product with use of the lowest energy consuming components available on the market. Avoid stand-by features. For example, about 70% of the energy consumption of a coffee machine during the lifetime in use is caused in the stand-by function. Only 30% of the energy consumption is directly connected with the purpose of the machine: making coffee. It is an extraordinary fact that only 10% of the total energy use during the lifetime is needed for heating the water! In the energy part during use there are a lot of environmental profits to harvest.

Using a *clean energy source* greatly reduces environmentally-harmful emissions, especially for energy-intensive products. Design the product so it uses the least harmful source of energy. Encourage the use of clean and renewable energy sources. An example is a solar heater which does not require energy for heating water during the summer.

Do not encourage the use of non-rechargeable batteries, for example; a walkman can be supplied with a battery charger, encouraging the use of rechargeable batteries. The best solution is to avoid batteries completely.

3.7.2 Reducing Waste Production During Use

A second step is to design the product so that the *fewer consumables* are required for its proper functioning. Some examples are:

Design the product to minimize the use of *auxiliary materials*, for example, use a permanent filter in coffee makers instead of paper filters, and use the correct shape of filter to ensure optimal use of coffee.

Minimize leaks from machines which use high volumes of consumables, for example, installing a leak detector.

Study the feasibility of *reusing consumables*, e.g. reusing water in the case of a dishwasher.

If an *auxiliary product* or consumable is to be improved in a project, it must be regarded as an individual product with its own life cycle. Ecodesign strategies must then be selected separately for each auxiliary product. Design the product to use the cleanest available consumables. Make sure that using the product does not result in hidden but harmful wastes, for example, by installing proper filters.

The product can also be designed to encourage consumers to *use products efficiently* and thus reduce waste. Mis-use of the product as a whole must be avoided by clear instructions and appropriate design.

3.8 Design for Long Life (Step 6)

3.8.1 Prolonging Product Life-time

The objective of the *initial life-time strategy* is to extend the *technical lifetime* – the time during which the product functions well – and the *aesthetic lifetime* – the time during which the user finds the product attractive – of a product, so that it will be used for as long as possible. All the principles that follow are aimed at this goal because the longer a product meets the user's needs, the less his/her inclination to purchase a new product.

It is, however, occasionally better not to prolong a product's lifetime; if the technical lifetime is much longer than the

Hints for step 5
Design for "Green" Use

Reducing energy consumption during use

1. Use the lowest energy consuming components available on the market.
2. Make use of a default power-down mode.
3. Ensure that clocks, stand-by functions and similar devices can be switched off by the user.
4. If energy is used to move the product, make the product as light as possible.
5. If energy is used for heating substances, make sure the relevant component is well insulated.

Reducing waste production during use

1. Design the product so that the user cannot waste auxiliary materials, for example, a filling inlet must be made large enough to avoid spillage.
2. Use calibration marks on the product so that the user knows exactly how much auxiliary material, such as a washing powder, to use.
3. Make the default state that which is the most desirable from an environmental point of view, for example, "no cup provided by drinks dispenser' or "double-sided copies".

aesthetic lifetime, a new balance must be sought. The technical lifetime must be made shorter or, preferably, the aesthetic lifetime must be longer. A shorter life is preferred if new, less energy-intensive alternatives are being developed.

Generally speaking we should design the product in modules so that the product can be upgraded by adding new modules or functions during its use when needed. For example, design a video recorder with a replaceable cover which can be removed, and eventually renewed. Further, make the most vulnerable components easy to dismantle for repair or replacement. Finally give the product an added value in terms of design and functionality so that the user will be reluctant to replace it.

3.8.2 Initial Lifetime Design Principles

Increasing the reliability and durability of a product is a familiar task to product developers. The most important rule to be applied is: develop a sound design and avoid weak links.

Hints for step 6
Design for Long Life

Initial lifetime design principles

1. Design the product in such a way that it needs little maintenance.
2. Indicate on the product how it should be opened for cleaning or repair, for example, where to apply leverage with a screwdriver to open snap connections.
3. Indicate on the product itself which parts must be cleaned or maintained in a specific way, for example, by colour-coded lubricating points.
4. Indicate on the product which parts or sub-assemblies are to be inspected often, due to rapid wear.
5. Make the location of wear on the product detectable so that repair or replacement can take place in time.
6. Locate the parts which wear relatively quickly close to one another and within easy reach so that replacements can be easily fitted.
7. Make the most vulnerable components easy to dismantle for repair or replacement.

The product-user relationship

1. Design the product so that it more than meets the (possibly hidden) requirements of the user for a long time.
2. Ensure that maintaining and repairing the product becomes a pleasure rather than a duty.
3. Give the product added value in terms of design and functionality so that the user will be reluctant to replace it.

Special methods, such as the failure mode and effect analysis, have been developed for this purpose.

Easy maintenance and repair are important to ensure that the product will be cleaned, maintained and repaired on time.

Choosing a modular structure or adaptable product makes it possible to "revitalize" a product which is no longer optimal from a technical or aesthetic point of view, thus enabling the product to still fulfil the (changed) needs of the user. Then the product can be upgraded by adding new modules or functions at a later date, for example, plugging in larger memory units in computers. Technically or aesthetically outdated modules can be renewed, for example, make furniture with replaceable covers which can be removed, cleaned and eventually renewed.

3.8.3 The Product – User Relationship

Classic design addresses the issue of the product-user relationship, to make an attractive product. But eco-designers, too, have to address this dimension of design. Now the aim is to reduce environmental impact by prolonging the use of a product.

One objective is to avoid trendy designs which may cause the user to replace the product as soon as the design pales or becomes unfashionable. Design the product's appearance so that it does not quickly become uninteresting, thus ensuring that the product's aesthetic life is not shorter than its technical life.

Most products need some maintenance and repair to remain attractive and functional. A user is only willing to spend time on such activities if he or she cares about the product. This principle of *Strong product-user relation* is aimed at intensifying the relationship between the user and the products.

Design the product so that it more than meets the (possibly hidden) requirements of the user for a long time. Ensure that maintaining and repairing the product becomes a pleasure rather than a duty. Give the product added value in terms of design and functionality so that the user will be reluctant to replace it.

3.9 End-of-life Design (Step 7)

3.9.1 End-of-life Design

A product's end-of-life system refers to what happens to the product after its initial lifetime. The end-of-life strategy is aimed to the reuse of valuable product components and ensuring proper waste management. Reusing the product, product components or materials can reduce the environmental impact of a product by reinvesting the materials and energy originally involved in its manufacture, and preventing additional hazardous emissions. If it is impossible to close the materials and

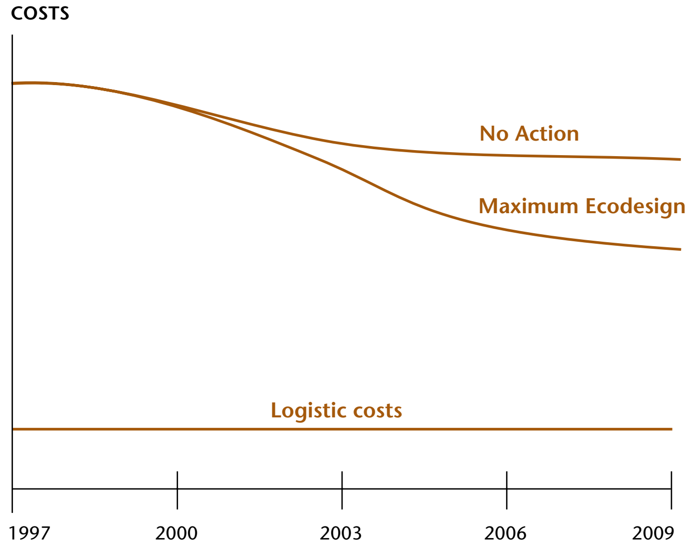


Figure 3.7 Take back costs. *The costs of take back of television sets change over time. Logistics costs are supposed to be constant [Eco-indicator 99, 1999].*

energy cycle in this way, safe incineration and waste disposal must be guaranteed.

The major issues for industry are the historical waste issue, the financing issue, and the material bans.

Firstly good design ensures that the construction does not become prematurely obsolete in a technical sense (to stimulate reuse of the product). It also ensures that the product can be dismantled in such a way as to ensure that the parts can be repaired, reused or disposed of separately.

Design for disassembly (from sub-assemblies to parts) means that the product should have a *hierarchical and modular design* structure; the modules can each be detached and remanufactured in the most suitable way. If non-destructive separation is not possible, ensure that the different *materials can be easily separated* out into groups of mutually compatible materials.

Secondly, cost is an important aspect of end-of-life management. An example of the emerging costs of take-back of televisions in Europe is given in the Figure 3.7. Televisions and computer monitors form 50-60% of the weight of the total waste stream of "browngood" products. It is expected that this figure will be even higher in the future due to the increasing portion of monitors. The graph shows clearly that a large reduction in the take-back costs of televisions can be achieved when the appropriate design, technological, economic and organisational conditions are fulfilled.

Thirdly, the presence of toxic material in a product will make disposal difficult, hazardous and costly. This is very of-

Hints for step 7
End-of-life Design

Design for disassembly

1. The product should have a hierarchical and modular design structure; the modules can each be detached and remanufactured in the most suitable way.
2. Use detachable joints such as snap, screw or bayonet joints instead of welded, glued or soldered connections.
3. Use standardised joints so that the product can be dismantled with a few universal tools – for example, use one type of screw.
4. Ensure easy accessibility of the product: use as few joints as possible and position joints so that the person responsible for dismantling the product does not need to turn it around or move it.
5. If non-destructive separation is not possible, ensure that the different materials can be easily separated out into groups of mutually compatible materials.

Design for maintenance and repairability

1. Design the product for dismantling to ensure easy accessibility of the product for inspection, cleaning, repair and replacement of vulnerable or innovation-sensitive sub-assemblies or parts, as detailed above.
2. Locate the parts that are relatively quickly worn out close to one another, so that they can be easily replaced.
3. Indicate on the product which parts must be cleaned or maintained in a specific way, for example; by using colour-coded lubricating points.

Design for recycling

1. Give priority to primary recycling over secondary and tertiary recycling.
2. Design the product for disassembly (from sub-assemblies to parts).
3. Try to use recyclable materials for which a market already exists.
4. If toxic materials have to be used in the product, they should be concentrated in adjacent areas so that they can easily be detached.
5. Integrate as many functions in one part as possible (a technique which can be used for this is Value Analysis).
6. Select one type of material for the whole product.
7. Use recyclable materials (such as thermoplastics, rather than laminates, filters, fire retardants and fibreglass reinforcements).
8. Avoid the use of polluting elements such as stickers which interfere with the recycling process.
9. Mark any parts made of synthetic materials with standardized material code.

ten the case with old materials that are scrapped after a long time, e.g. when removing a house. Here we may find PCB in walls and in joints; there may be mercury in electric equipment, such as switches, and lead in e.g. cables. Today similar difficulties are valid for some electronic equipment where flame retardants, often made from eco-toxic brominated organic compounds, are present.

Rules for how to handle hazardous wastes are becoming increasingly severe and costs are increasing. It is obvious that such materials should be avoided in any products.

3.9.2 Reuse of Products or Parts

The preferred option in disposal is to reuse the product as a whole, either for the same or a new application. The more the product retains its original form, the more environmental merit is achieved, providing that take-back and recycling systems are developed simultaneously.

This is best achieved if the product is given a classic design that makes it aesthetically pleasing and attractive to a second user. It is also important that the construction is sound so that it does not become prematurely obsolete in a technical sense.

The reuse option is also valid for parts of a product. This is well established for e.g. spare parts of cars, but regrettably many products end up in the incinerator or at land fill sites even though they still contain valuable components. A product may be reused if parts are replaced, and parts in a product may be reused even if the product as such has to be scrapped. It is useful to consider whether these components can be reused, either for the original purpose or for a new one. Remanufacturing and refurbishing, in the sense of restoring and repairing the sub-assemblies, is then usually necessary.

3.9.3 Recycling of Materials

Recycling, that is, reuse of the *material* in a product, is a common strategy because it requires relatively little time and only small investments: make the product so that it can be easily disassembled and use suitable materials in it. Another reason for the popularity of recycling is that it often brings financial benefits as well. The importance of recyclability is also easy to communicate both inside and outside a company.

Recycling requires that a system is set up for collecting the material, send it to the proper companies, and perhaps also a system for refunding. However, there used to be a tendency to claim that a product was recyclable even if no attempts were made to set up a take-back and recycling system. This tendency is now diminishing thanks to increased consumer and governmental awareness. For example, the US Federal Trade Commission prohibits the claim that a product is recyclable if the take-back infrastructure is not in place; and "thermal recycling" (incineration for recovering the energy value) is not regarded as recycling at all. If recycling is preferred to other strategies with more environmental merit, then the decision should be reconsidered.

There are several levels of recycling which together form a "recycling cascade": primary recycling (meant for original application); secondary recycling (meant for a lower-grade application; and tertiary recycling (such as decomposition of plastic molecules into elementary raw materials). These issues are discussed further in Chapter 10.

3.9.4 Incineration

If reuse and recycling are out of the question, the next best option is incineration with energy recovery (sometimes presented as "thermal recycling"), as is the case in modern waste incineration plants.

The more toxic materials there are in a product, the more the responsible party has to pay for its incineration. Toxic elements should therefore be concentrated and easily detachable so they can be removed, paid for and treated as a separate waste stream.

Study Questions

1. What is the relation between Ecodesign strategies and Life Cycle Assessment (LCA)?
2. Which are the direct impacts on human health by using toxic materials?
3. Give some examples of alternatives for exhaustible (non-renewable) materials.
4. Give a short description of the dematerialisation process.
5. What kinds of techniques are available to reduce the impact on the environment during production?
6. Which factors influence the impact on the environment in the transport phase of a product life cycle?
7. What is exactly: Design for "green" use?
8. Describe the relation between "Design for long life" and the "Brundtland report".
9. Why is incineration the last alternative of the "End-of-life" step?
10. What is the purpose of the product review step?

Abbreviations

ADI	Acceptable Daily Intake.
ALARA	As Low As Reasonable Acceptable.
DNA	Desoxyribo Nucleic Acid.
EMAS	Environmental Management and Auditing System.
EMS	Environmental Management System.
IARC	International Agency for Research and Cancer.
ISO	International Organisation of Standardisation.
LCA	Life Cycle Assessment.
LD	Lethal Dose.
MET	Material, Energy and Toxicity.
OECD	Organisation for Economic Cooperation and Development.
PAH	Poly Aromatic Hydrocarbon.
PCB	Poly Chlorinated Biphenyls.
PVC	Poly Vinyl Chloride.
REACH	Registration, Evaluation and Authorisation of Chemicals.
RPD	Renewing Product Development.
SCM	Supply Chain Management.
UNEP	United Nations Environmental Program.

Internet Resources

International Agency for Research on Cancer (IARC)
http://www.iarc.fr

The Centre for Sustainable Design
– ETMUEL Project: Ecodesign Tools
http://www.cfsd.org.uk/etmuel/tools.htm

Design for Environment (DfE) Guide
of the Industrial Research Assistance Program
– National Research Council of Canada
http://dfe-sce.nrc-cnrc.gc.ca/home_e.html

American Society of Preventive Oncology
http://www.aspo.org

Centre for Design – Ecodesign Guidelines (DIA)
http://www.cfd.rmit.edu.au/programs/sustainable_products/ecodesign_guidelines_dia

Greywater Recycling & Irrigation Systems
http://www.greywater.com.au

PRé Consultants – Ecodesign
http://www.pre.nl/ecodesign/default.htm

Tennessee College of Architecture and Design
– Ecodesign Resources
http://www.ecodesignresources.net

United Nations Environment Programme (UNEP)
and Ecodesign
http://www.uneptie.org/pc/sustain/design/design-subpage.htm

PRé Consultants: life cycle tools to improve
environmental performance & sustainability
http://www.pre.nl/ecodesign/default.htm

EcoDeNet ecoDesign Promotion Network
http://www.ecodenet.com/ed2001/

UNEP Sustainable consumption site
http://www.uneptie.org/pc/sustain/design/design-subpage.htm

EnviroWindows. Environmental Information for Business and Local Authorities
http://www.ewindows.eu.org/ManagementConcepts/Ecodesign

Industrial Designers of America (IDSA) ecodesign section
http://www.idsa.org/whatsnew/sections/ecosection/

The Centre for Sustainable Design,
Surrey Institute of Art & Design, University College, UK
http://www.cfsd.org.uk/etmuel/tools.htm

The Journal of Sustainable Product Design - Online
http://www.cfsd.org.uk/journal/index.html

Design for Environment (DfE) Guide, Industrial Research Assistance Program of the National Research Council of Canada
http://dfe-sce.nrc-cnrc.gc.ca/home_e.html

EcoDesign Guidelines (DIA), Centre for Design, RMIT University, Melbourne, Australia
http://www.cfd.rmit.edu.au/programs/sustainable_products/ecodesign_guidelines_dia

REACH Directive of the EU
http://europa.eu.int/comm/environment/chemicals/reach.htm