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BSI Standards Publication

Design for manufacture, assembly, disassembly and end-of-life processing (MADE)

Part 3: Guide to choosing an appropriate end-of-life design strategy

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Foreword

Publishing information

This part of BS 8887 is published by BSI Standards Limited, under licence from The British Standards Institution, and came into effect on 30 June 2018. It was prepared by Subcommittee TDW/4/7, *BS 8887 design for MADE*, under the authority of Technical Committee TDW/4, *Technical product realization*. A list of organizations represented on these committees can be obtained on request to their secretary.

Relationship with other publications

BS 8887 is published in a number of parts including:

- *Part 1: General concepts, process and requirements*; and
- *Part 2: Terms and definitions.*

Part 1 to Part 99 are general MADE standards; Part 100 to Part 199 are related to manufacture and assembly; and Part 200 to Part 299 are related to disassembly and end-of-life.

Use of this document

As a guide, this part of BS 8887 takes the form of guidance and recommendations. It should not be quoted as if it were a specification or a code of practice and claims of compliance cannot be made to it.

Presentational conventions

The guidance in this standard is presented in roman (i.e. upright) type. Any recommendations are expressed in sentences in which the principal auxiliary verb is "should".

Commentary, explanation and general informative material is presented in smaller italic type, and does not constitute a normative element.

Where words have alternative spellings, the preferred spelling of The Shorter Oxford English Dictionary is used (e.g. "organization" rather than "organisation").

Contractual and legal considerations

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

Compliance with a British Standard cannot confer immunity from legal obligations.

Introduction

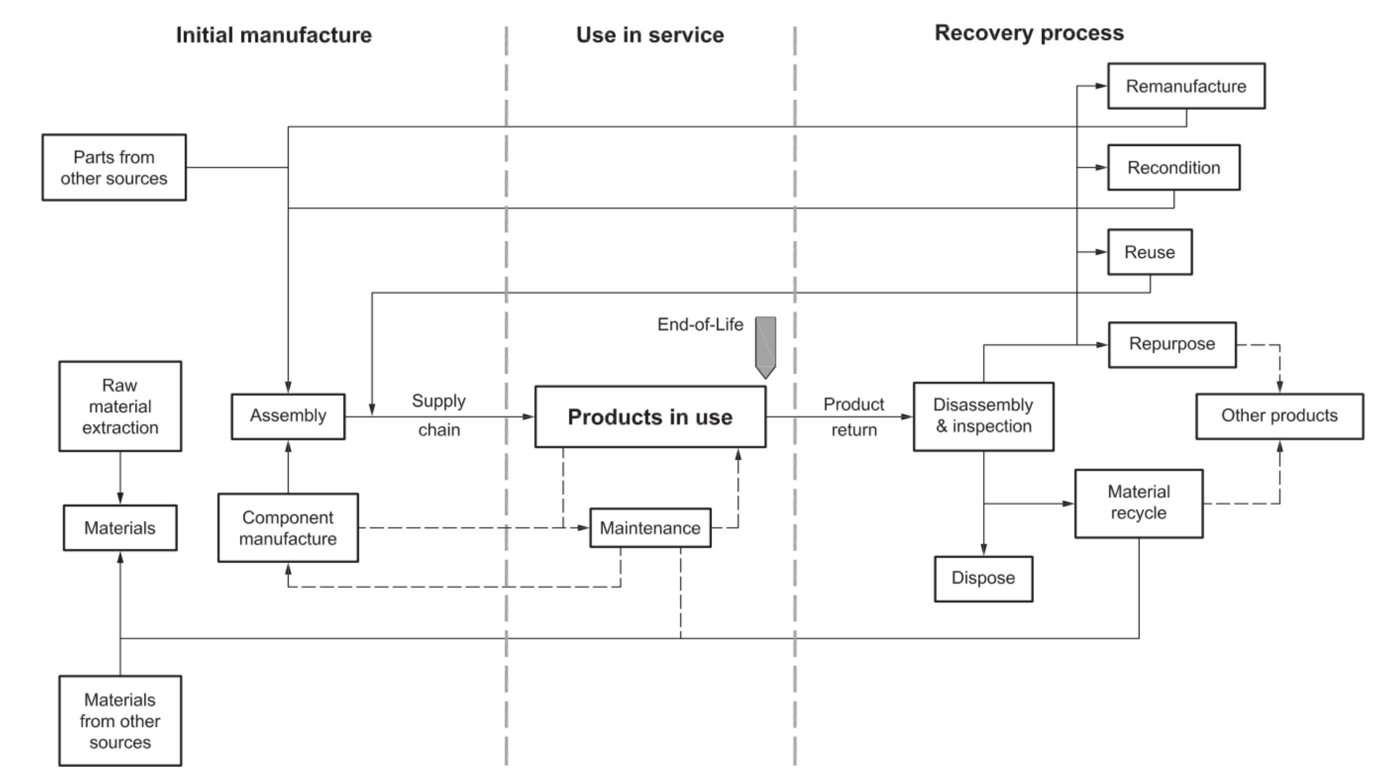
With the rising costs of raw materials as more easily available sources become exhausted, and with the environmental need to reduce pollution in line with the waste hierarchy specified in the Waste Framework Directive (2008/98/EC) [1], it is desirable that new products are designed with the potential to be used again in some way at the end of their life in service. This maximizes the investment made in extracting and processing the raw materials, which is a high proportion of the costs of producing a product.

At the end of a life in service, the decisions on how to use a product, or its components, for another period of service can be made much more easily and cheaply if the original design incorporates features intended to aid one of several options available. Any extra costs incurred in the initial production can be recovered several times, over further lifecycles.

To decide which option is appropriate, there are a number of factors to be considered. This guide is intended to help with those considerations and give some guidance on the potential advantages of designing for further use.

Figure 1 illustrates the typical material flow around a product cycle if maximum advantage is taken of the opportunities for further use. For clarity, it does not include inspection and quality control activities.

Figure 1 — *Product materials lifecycle*



1 Scope

This British Standard provides guidance on the general policies and specific decisions to be made when considering the potential for manufactured products (see **3.1**) and/or their components, to be designed to have a recoverable value at the end of their life in service. Guidance is given on the factors to be considered during the design process which influence further life.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this part of BS 8887, the terms and definitions in BS 8887-2 and the following apply.

3.1 manufactured product

complete product produced singly, in batches, or in bulk by an industrial manufacturing system

[SOURCE: BS 7000-2:2015, **3.14**]

3.2 new materials

materials derived from natural sources, not previously used for any other purpose

3.3 production

complete process from component manufacture and processing to completed assembly and finishing including associated verification (quality control)

4 General

4.1 The environmental case

As sources of easily available natural resources become exhausted and their costs rise, it is no longer viable to simply dispose of products or their packaging at the end of a single life in service. Some form of end-of-life recovery and further use of materials, parts, component assemblies and complete products should be taken into account during the initial planning and design of new products in order to provide design changes to aid the end-of-life process.

The environmental advantages are significant. They include the reduction of waste disposal on land or at sea and associated pollution; increased efficiency of resource use; and the potential to reduce or avoid the environmental impact of extraction and processing.

Whilst legislation such as the WEEE Directive [2], voluntary standards such as Ecolabels and Cradle to Cradle, and policy and private initiatives such as the Circular Economy have increased in scope and application, effective guidance as to the choices available to design teams at an early stage has been a relatively neglected area to date. This British Standard aims to address this.

NOTE For further information on Ecolabels, see http://ec.europa.eu/environment/ecolabel/index_en.htm; on Cradle to Cradle, see www.c2ccertified.org [last viewed 18 May 2018].

If full advantage is to be taken of the availability of components for further use, the possibility of designing to incorporate components or sub-assemblies which have been used before should be taken into account, rather than assuming all parts are to be made from new materials. Clearly, such parts would need to be available in sufficient quantity and quality at a cost the same as or less than that of new manufacture.

Packaging should be part of the design thinking. The amount should be reduced from current levels. Wherever possible, packaging should itself have a further use, and hence a value, beyond the delivery of the product and not simply be disposable.

4.2 The business case

The balance between any additional production costs and the cost advantage of inbuilt end-of-life value is key to the business case for further use policies. Traditional business models are based on a linear model with a policy of direct sales, perhaps including some after-sales servicing for an initial period, with the purchaser making any decisions as to the use and eventual disposal of the product when it is "written-off" as valueless.

More recently, some industries have moved to some form of contract lease agreement where the product ownership is retained by the manufacturer, or a related agency, which provides the use of the product to the customer. The customer usually undertakes day-to-day routine maintenance tasks and meets the costs of any fuel or other expendables. The manufacturer carries out major maintenance and upgrades or replaces the product, as necessary. Examples can be seen in the aircraft industry, where airframes and engines are often on separate contracts; in the provision of railway rolling stock to the train operators in the UK; and some areas of shipping, particularly for cargo and container shipment. In these examples, the businesses involved include a major activity where end-of-life products are refurbished, and where necessary re-certified, for further use by another customer. Other industries have taken up a model of buying back both whole products and the replaceable parts available from routine maintenance and putting them back into service. This has been widely adopted in the automotive industry, which is moving towards contract provision for the initial life-in-service, and also for some consumer electronics, such as mobile phones.

For a leasing environment, the manufacturer, or its agents, can directly recover the value, since parts put back into service do not have the costs of extracting and processing the materials. Where major sub-assemblies or components, such as electric motors, structural components or circuit boards, can be used again after appropriate checks and refurbishment, significant savings can be made. Under these circumstances, more favourable initial terms might be offered to customers, making the product more attractive.

Where any recognized system of further use is in place, a policy of designing products taking this into account should be established to realize the maximum business advantage. The investment in processing raw materials, from extraction to manufacture as component parts, can be spread over a series of product lives, reducing the associated costs of each cycle. Inevitably, this means that the full return on new product development can only be made over a significantly longer period than has been the norm, but could be much higher giving the OEM (original equipment manufacture) an incentive to retain an interest.

Where no general system for recovering end-of-life products already exists, either at a company or industry level, the costs of setting up such a system should be carefully evaluated. Long-term planning can offset these costs over time. If a product line is designed with such a system in mind, a sufficient quantity of end-of-life products would not be available for the system to become fully operational until a number have been returned to the manufacturing system at the end of their initial use. This allows time to invest in necessary plant, train operatives and carry out test runs as the number of products builds to a steady state. Thus investment can be spread over a time period, perhaps of years, depending on the normal lifetime in service. If there are significant changes in the background assumptions of costs, material values, etc., there is time to modify decisions if deemed necessary.

When purchasing products designed for further use, their potential value at the end of the life in service should be taken into account to offset the original cost. Normal depreciation rates should be adjusted to account for this in budgeting; for example, "writing-off" periods should be replaced by "optimum value recovery" times. There might be a balance to be struck between rates of depreciation, recoverable value and the cost of replacement.

Opportunities to incorporate existing components from end-of-life products into design thinking should be actively pursued. Such components are likely to be significantly less costly than those made from raw materials, provided they can be available in sufficient quantities and quality to satisfy the market.

4.3 The marketing case

The potential for a product to retain a significant value at the end of its life in service becomes a key factor in marketing. That value can only be realized by the manufacturer if there is a clear buy-back path for the user to return the product to the industry, via the OEM, the retail source or a separate contracted enterprise.

For industrial products, whether the supply is direct or through an intermediary, the user is usually identifiable and often has a direct relationship with the OEM for spare parts and maintenance. It is therefore easier for the product to be returned at the end of its life in service in either a sale or lease environment.

For consumer products there are several business models possible, and the marketing process has to be adapted for each. However, the key factor is that the product has a value at the end of its life in service. This could also make it more attractive to the customer, giving them an incentive to keep it in good condition if they receive some reward for returning it to the manufacturing system.

5 The end-of-life design choice

A key decision in the design process is which of the end-of-life options are best suited to the product context. This decision can affect the design of some components, the way the product is assembled and what materials are selected. The options are given in a) to f). For larger, more complex products it is likely that different sub-assemblies are designed for different options.

BS 8887-1 identifies six pathways for end-of-life products to follow:

a) remanufacture;

b) recondition;

c) reuse;

d) repurpose;

e) recycle; and

f) disposal.

The first four imply a system to return the product to the OEM, or otherwise agreed organizations, for further useful lifecycles. Recycle assumes the product (or its components) would go through a process for the recovery of its materials for further use. Disposal implies that the costs of recovering the materials is greater than any potential value.

To retrieve the most value at the end of useful life-in-service, product design teams should decide early in the product development process whether to design the products to recover some of the value invested in their production. This decision should balance any costs of providing additional features against the potential for value recovery. If costs cannot be recovered, generating an acceptable level of profit, the products are assumed to be recycled or disposed of.

The general requirements, relationships, advantages and disadvantages, in this context, of all six potential pathways are set out in Table 1. These decisions can be made in accordance with broad organizational (or contractual) policies, made at a senior level, or be specific to a particular range of products or components and made by the design team. This British Standard is intended to aid these decisions at whatever level they are made. (See BS 7000-2 for levels of decisions.)

NOTE These options do not include lubricants, sealants, adhesives and similar chemical products which are used during manufacture or use.

Table 1 is in the order of environmentally preferable solutions. It can be considered as a decision tree, where, if the requirements of a higher option are met, it becomes the preferred solution. If not, the next item in the table should be considered.

Table 1 — *End-of-life pathway choices*

Remanufacture (see 6.2)	
Requirements	A functional market requirement likely to remain stable for several lifecycles (perhaps with cosmetic changes), giving a prime market position.
Advantages	Has the maximum potential to realize the initial investment in energy, materials and manufacturing facilities. Later product cycles can be upgraded to continue market interest.
Disadvantages	Might be overtaken by new technological or legal developments. Requires a long-term commitment to the product line at company level. The need to maintain warranty commitments, by making products more durable, becomes an important design consideration.
Recondition (see 6.3)	
Requirements	A functional market requirement likely to remain stable for several lifecycles (perhaps with cosmetic changes). A market advantage can be derived from the ability to offer significant price reductions.
Advantages	Has significant potential to realize the initial investment in energy, materials and manufacturing facilities.
Disadvantages	Further product cycles inevitably lead to some degradation and the likelihood of increasing competition. The design might be overtaken by new technological or legal developments or changes in aesthetics or fashion. Requires a long-term commitment to the product line at company or industry level.
Reuse (see 6.4)	
Requirements	A functional market requirement likely to remain stable for several lifecycles, with no expectation of functional improvement.
Advantages	Some recovery of initial investment in energy and materials. Less likely to be overtaken by new technological or legal developments. Offers a low cost acquisition option for second life customers with limited means.
Disadvantages	Vulnerable to market changes, technological advances and competition.
Repurpose (see 6.5)	
Requirements	The product, or a significant number of its components, needs to have standard interfaces which take advantage of its capacity for further use within a new market. A modular design system could be considered.
Advantages	Some recovery of initial investment in energy and materials. New potentials for repurposing might become apparent during its lifetime.
Disadvantages	New uses envisaged during the initial design might not materialize, particularly with longer lifecycles. Products also need to be easy to recycle or dispose of.

Table 1 *(continued)*

Recycle (see 6.6)	
Requirements	Product needs to be easy to disassemble into its component materials or compounds with minimum degradation. There needs to be a clear recycling route.
Advantages	Some recovery of initial investment in energy of material extraction. (This might be particularly appropriate where the technology of the product is likely to be superseded before the service life expectancy and the materials in question have intrinsic value.)
Disadvantages	No recovery of initial investment in manufacture and assembly.
Disposal (see 6.7)	
Requirements	Might be vulnerable to rapidly changing technologies, market expectations or competition. Recoverable value less than costs of any of the other pathways. All materials need to be designed for safe disposal as fuel or landfill. Any hazardous materials need to be appropriately and clearly identified.
Advantages	No requirements for an end-of-life capability. Materials need to be chosen for safe and easy disposal by the customer.
Disadvantages	The entire investment in manufacturing energy and material (as well as design and development costs) has to be recovered in a single product cycle, along with profits for all stakeholders, resulting in a higher product cost to the customer or a reduction in perceived quality (throw-away).

Once choices have been made from the options in Table 1, the design can be focused on addressing those requirements indicated as part of the design specification.

All of these options also apply to the design of jigs and fixtures, packaging, palleting and other ancillary materials, as well as parts replaced within the lifecycle during routine maintenance (e.g. filters, batteries, ink cartridges, friction pads).

6 Design implications

*COMMENTARY ON CLAUSE **6***

This clause is concerned with the types of design decisions to be taken for each of the choices outlined in Table 1. The first four imply a strong need to design for ease of disassembly. Clause 7 covers those production details of particular concern.

6.1 General

Where lifecycles are longer than the likely production run of the product, some provision should be made to retain the information necessary to process end-of-life products efficiently using any features intended for that process.

Information should include:

a) the design specification, including material specifications, with any reference to specific features incorporated to aid further use;

b) any additional relevant information on specific batches or individual products which deviate from the main specification for any reason (customized products, upgrades, manufacturing or material changes, etc.); and

c) details of any jigs, fixtures and tooling necessary to disassemble and reassemble the products for the next cycle.

For products designed to be recycled, only the retention of material specifications are necessary (perhaps as markings on the components).

Where cumulative damage is expected to occur over a number of lifecycles (wear and tear, structural fatigue, galvanic or electrolytic corrosion, etc.) some facility for the number of service cycles to be permanently recorded on a component might be necessary.

If a product has experienced an extreme overload event in use (perhaps anticipated within its design capacity as an "ultimate" case) where its ability to continue in service has been compromised, components which are assessed as still viable (perhaps after testing) should be returned to the normal process and the rest sent for recycling or disposal.

Where a complex product can be broken down into separate modules by the user or consists of components assembled in different configurations for different tasks (e.g. kitchen blender, excavator), each module can be considered as a separate product when evaluating the options. The interfaces between modules should be standardized for interchangeability.

6.2 Design for remanufacture

*COMMENTARY ON **6.2***

*BS 8887-2:2009, **3.34** defines remanufacture as "returning a used product to at least its original performance with a warranty that is equivalent or better than that of the newly manufactured product".*

For further guidance on remanufacture, see BS 8887-220.

For remanufacture, the functional state of the product should be testable and parts subject to wear or degradation should be easily replaceable. It might also be necessary to consider replacement of those parts of the product, which could be upgraded due to, for example, technological improvement or changes in legislation. Products controlled by software should have appropriate access for checking and re-programming.

Designers should take into account the level of disassembly necessary to test the product's condition and take any remedial action such that a warranty equal to or better than the original can be issued. This should include any non-destructive functional testing and the ability to refurbish or replace any worn or degraded parts. Design records should include necessary test methods and acceptable limits of functional operation. These often correspond to any acceptance tests carried out during the original manufacture, but might also include dimensional and other checks to locate any damage which could have occurred during use.

Any fastener systems which need to be removed for disassembly should be easily accessible. Their materials should be chosen to avoid any corrosion of the fasteners, or their mating parts, which might make them difficult to remove or replace. Any jigs or fixtures necessary for re-assembly should be retained from the original assembly, or sufficient information recorded for them to be reproduced.

NOTE When the product manufacture ends, components can still be remanufactured in order to provide spare parts.

6.3 Design for reconditioning

*COMMENTARY ON **6.3***

*BS 8887-2:2009, **3.30** defines recondition as "returning a used product to a satisfactory working condition by rebuilding or repairing major components that are close to failure, even where there are no reported or apparent faults in those components".*

For further guidance on reconditioning, see BS 8887-240.

After reconditioning, the product might then be given a warranty equivalent to or lower than the original product. This implies that the functional state of the product needs to be testable and any parts likely to need rebuilding or repairing are easily removable.

Some products cannot be reconditioned so as to achieve satisfactory performance requirements. (This might be because of, for example, legal requirements to use “new” materials for particular purposes.)

NOTE 1 BS 8887-2:2009 defines recondition and refurbish as synonymous.

NOTE 2 When the product manufacture ends, this option might no longer be available and other choices could be viable.

6.4 Design for reuse

*COMMENTARY ON **6.4***

*BS 8887-2:2009, **3.38** defines reuse as "operation by which a product or its components are put back into use for the same purpose at end-of-life".*

The product might be given a warranty equivalent to or lower than the original product.

Products are disassembled into components, which can then be inspected or tested before being re-assembled into more of the original product type. Assembly tolerances should remain within acceptable limits during use.

*NOTE For the options given in **6.2**, and **6.3** viable components might have a market as replacement spares, even when the original production run has ended.*

6.5 Design for repurposing

*COMMENTARY ON **6.5***

*BS 8887-2:2009, **3.37** defines repurpose as "utilize a product or its components in a role that it was not originally designed to perform".*

No system of product cycles can last forever. Inevitably the requirements for a particular product range changes beyond the capacity of a particular original design to meet. For products such as some medical equipment, options for re-introducing previously used parts into “new” products are not currently allowable. Repurposing could be more easily expedited if the product has a modular design so that major components or sub-assemblies can be separated without degradation to be reassigned for other purposes. Designers should take into account the use of pre-existing components in new designs, with their potential for considerable cost savings.

6.6 Design for recycling

*COMMENTARY ON **6.6***

*BS 8887-2:2009, **3.32** defines recycle as "process waste materials for the original purpose or for other purposes, excluding energy recovery".*

Where a whole product or any of its components cannot be refurbished for any reuse, the individual materials should be separable to be returned for reprocessing. There is no need to add them to general recycling streams, since they are known materials and can be processed more efficiently. Materials which have been used several times could have become degraded to the point where their properties can no longer be reliably guaranteed and their potential for further use is limited. However, they might still serve as fillers, balance weights, or for other “bulking” purposes (for example, rubber recovered from used tyres has been used for road surfacing).

Designers and engineers should also be aware of developments in the chemical recycling of polymers, by which the materials are depolymerized back to the monomer, enabling original properties to be recreated. This technical approach is in its infancy, but chemical recycling of nylon carpets has been commercialized in the USA[1] and Italy[2], and has been developed for polyester textiles (separating cotton as well) in both the USA[3] and UK[4], although not yet commercialized, and for PET in Canada[5].

Also near to market is chemistry which enables a thermoset polymer to become a thermoplastic, and therefore recyclable, on specific environmental triggers, such as hydration, pressure or temperature, which would be introduced in a recycling facility.[6]

6.7 Design for disposal

*COMMENTARY ON **6.7***

*BS 8887-2:2009, **3.12** defines disposal as "any operation which is not recovery even where the operation has as a secondary consequence the reclamation of substances or energy".*

Where there is no alternative, products, components or materials which cannot be returned to the product cycle for any economically viable use should be selected to be safely disposed of, either as fuel, soil nutrient or landfill.

Composting and anaerobic digestion of biodegradable materials, including biodegradable polymers, composites and chemical components, also fall under the definition of disposal. Some fossil-based materials are biodegradable in addition to materials from renewable sources, and the range of fossil-based materials designed to be biodegradable is increasing.

Designing with biodegradable materials is likely to become increasingly important as one means of avoiding the accumulation of inert plastics in the oceans through the incremental loss of fibres and chemical products in consumer washing wastewater and industrial effluent. (They should not, however, be seen as a solution to consumer litter or industrial carelessness.)

Such materials should conform to the current versions of the relevant standards (for compostability: ISO 17088, BS EN 13432 or BS EN 14995, or ASTM D6400-12 or ASTM D6868-17 for anaerobic digestion feedstock: PAS 110). These standards do not include materials which are only degradable by non-biological agents, such as oxygen or light.

Where direct safe disposal is not possible, processes should be available to render materials inert. In extreme cases (e.g. radioactive or highly toxic materials), the costs of such processes might have to be factored into the initial costing.

7 Production and use implications

7.1 General

*COMMENTARY ON **7.1***

This subclause is not intended to be a comprehensive guide to production, which is available from other sources, but only to refer to those particular considerations needed for multi-life products during the design phase. This includes any inspecting, testing and refurbishing products or components before returning them to the main production system.

One of the advantages of products designed for ease of disassembly is that they might be easier to assemble, both for the original manufacture and maintenance. However, the product could be slightly heavier, less efficient or require some constraints to its appearance or shape (e.g. visible fasteners or component marking).

1 See <https://shawfloors.com/shaw-sustainability/post-consumer-carpet-recycling> [last viewed 18 May 2018].
2 See <http://www.econyl.com> [last viewed 18 May 2018].
3 See <https://resource-recycling.com/plastics/2017/01/06/innovation-improves-depolymerization-of-textile-polyesters> [last viewed 18 May 2018].
4 See <www.wornagain.co.uk> [last viewed 18 May 2018].
5 See <www.loopindustries.com> [last viewed 18 May 2018].
6 See <www.connoratech.com> [last viewed 18 May 2018].

To fully exploit the multiple lifecycles concept, the use of components or materials recovered from products used earlier should always be taken into account. These need to be available in sufficient quantity and quality to meet the production volumes envisaged in a timely way. For longer production runs, arrangements should be in place for components from products at the end of their life to be remanufactured or reconditioned to become part of further production (see 6.2 and 6.3).

7.2 Materials and components sourcing

In selecting materials and components the following should be taken into account to maximize the potential of end-of-life options.

a) Use materials which are as ubiquitous and abundant as possible.

b) Use materials and components which are as local in origin as possible.

c) Use less dense (lighter) materials. This contributes to lower energy or materials requirements of the product in use which outweigh any additional energy and material embodied in the product. Construction products and products requiring toughness are good examples of where this might apply.

d) Use materials with low embodied energy (that is, the energy used to extract, harvest or gather them from source, process and transport to the manufacturing facility).

e) Maximize the use of materials which can be extracted, harvested or gathered from source with zero or minimal collateral material not intended for the product, reducing waste.

f) Use renewable materials.

g) Where certification schemes exist covering environmental stewardship of natural resources (such as that of the Forestry Stewardship Council), use materials approved under an appropriate scheme and Chain of Custody from plantation/forest to immediate supplier.

h) Reuse fit-for-purpose components and piece parts.

i) Use 100% reclaimed for reuse materials.

j) Use recycled fit-for-purpose components and piece parts.

k) Use 100% recycled or part recycled materials.

l) Use recyclable materials which allow optimization of quality, energy, waste and emissions in the recycling process.

m) Use recyclable materials and components for which collection for recycling is well established for the product customer group (commercial, household), or which customers can recycle on site or easily despatch for recycling.

n) Use recyclable materials and components for which there is a prospect of collections being established.

o) Avoid pigmented plastics (for easier recycling) where possible.

p) Use chemical additives (including metals) which are environmentally and physiologically benign.

p) Use chemical additives (including metals) which are environmentally and physiologically benign.

q) Use chemical additives (including metals) which are less environmentally and/or physiologically toxic or polluting than the current additives for the product category.

r) Use biological processes which are environmentally and physiologically benign.

NOTE For further information on the sustainable use of materials, see BS 8905.

7.3 Manufacturing processes

In specifying manufacturing processes, the following should be taken into account to maximize the potential of end of life options.

a) Materials.
   1) Use net shape forming processes.
   2) Maximize precision of materials processing down to the smallest scale necessary for maximum material economy.
   3) Maximize capture and reuse of materials arising as waste during process (aim for zero waste residue from process).
   4) Minimize particulate emissions to air, land and water.
   5) Avoid materials which are/will be classified as hazardous as waste or at end-of-life.
   6) Pretreat any unavoidable hazardous waste to reduce the hazardous nature.

b) Energy.
   1) Consider alternative process technologies which are more efficient.
   2) Minimize energy input to chosen process.
   3) Maximize energy efficiency of chosen process.
   4) Maximize capture and use of waste process energy (both heat and power).

c) Water.
   1) Minimize use of process water.
   2) Maximize capture and reuse of waste water, cleaned as necessary.

d) Chemicals.
   1) Minimize emissions of toxins and pollutants to air, land and water.
   2) Avoid chemicals which are/will be classified as hazardous as waste or at end-of-life.

7.4 Product use

With respect to the impact of the product in use, the following should be taken into account during the design.

a) Minimize energy and water requirements and maximize efficiency in the use of energy and water, other resources and any catalysts.

b) Consider any environmental, customer or commercial benefits of providing the utility of the product to the customer without the sale of the product and whether there are design implications.

c) Incorporate sensors and information systems to provide feedback on product performance.

d) Incorporate sensors and information systems to provide feedback on the condition of materials and components.

e) Maximize the potential for upgrading and serviceability of the product.

7.5 Demanufacturing processes

Most materials used in industrial societies require mechanical operations to demanufacture and recycle them. The main environmental issues arising from this are the use of carbon-positive energy and emissions of toxins and pollutants from materials (as well as from combustion of fuel for machinery). The optimum approach to materials recycling involves the transformation of a material up or down in quality to a level suitable for use within a designated new product or class of product, through non-mechanical (microbial, biochemical, benign chemical) or energy efficient and zero carbon mechanical processes.

Materials might have been chosen at earlier stages of the design process which enable this approach; otherwise the following checklist enables the energy and emissions impacts of demanufacturing and recycling to be minimized.

a) Materials, piece parts and components.
   1) Minimize non-biodegradable materials.
   2) Use compatible materials (in, for example, chemical, electrolytic, polymer migration terms).
   3) Avoid mixing as far as possible of component and piece part materials which reduce the efficiency of recycling, e.g. metal inserts in plastic parts.
   4) Maximize standardization of component variations.
   5) Select materials with similar component life to match design life of assembly.
   6) Avoid composite materials employing adhesives.
   7) Group harmful materials in separate, accessible modules.
   8) Avoid combining ageing and corrosive materials.
   9) Minimize the number of piece parts, either within the product or sub-assembly as designed, or by redesigning the product or sub-assembly, or by using different manufacturing methods which allow the product or sub-assembly to be made in fewer pieces or in one piece.

b) Joining.
   1) Minimize the number of fixings and fasteners and standardize the types and sizes.
   2) Subject to security and safety considerations, use joining technologies and methods which enable easy separation of components and materials.

c) Coatings/finishing.
   1) Avoid secondary finishing such as painting, coating or plating.
   2) Choose durable materials in preference to protective coatings.

7.6 End-of-life processing

The following should be taken into account to maximize the potential of end of life options.

a) Provide convenient access to valuable and reusable parts.
b) Provide clear identification of replacement/repair modules.
c) Protect sub-assemblies against soiling, corrosion and erosion.
d) Code or otherwise identify parts to facilitate recycling and audit trails to production data. For plastic parts above 50 g, mark in accordance with BS EN ISO 1043 (all parts) and BS EN ISO 11469.
e) Code or otherwise identify materials, including surface coatings and alloys, to facilitate recycling and audit trails to production data.
f) Provide all information to assist recycling in documentation, whether in print or electronically.

8 Verification implications

Quality control, in a multiple lifetime environment, takes on a more complex role. Before a product goes into service, its suitability for use should be verified at appropriate stages during its production. For a single life-in-service product, this usually consists of some comparison between the actual product and the design requirement as documented in the design documentation. This might still be possible for some of the options where the product goes back into service in a similar condition to its original specification (such as remanufacture or reconditioning).

For reuse and repurposing, appropriate verification requirements should be put in place. Recycling and disposal require no verification within the design of the current product.

9 Longer term implications

If a product is to have a significant value at the end of its life in service, the user needs to take some responsibility for its care and maintenance during that time. Appropriate storage (taking account of suitable temperature and humidity levels), avoidance of anything more than fair wear and tear in operation, any necessary cleaning or other routine care and protection, and the regular replacement of lubricants, coolants, batteries, or other parts, subject to degradation in service, would need to be undertaken by the user.

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