Chapter 2
Designing for Sustainability

Helen Lewis

Abstract Packaging for sustainability initiatives can be identified through strategic and operational planning processes, but they are primarily delivered through design. Packaging design is an already complex process that considers many aspects of marketing, packaging function and cost. Designing for sustainability adds further complexity to this process. To integrate these new requirements into the packaging design process efficiently and effectively we propose the use of a packaging sustainability framework. A framework is presented that applies a triple bottom line approach to packaging design based on four design principles: effectiveness (fit for purpose), efficiency (efficient use of materials, energy and water), cyclic material flows (renewable/recyclable materials and minimal waste) and safety (non-polluting and non-toxic). Each principle is outlined, and practical design strategies and case studies are provided to demonstrate their application.

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H. Lewis (✉)
Centre for Design, RMIT University, GPO Box 2476, Melbourne, VIC 3001, Australia
e-mail: lewis.helen@bigpond.com

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2.1 Introduction

Most businesses have a process for product development that encompasses packaging optimisation or redesign and new packaging design. The process is generally led by a packaging specialist, either within or external to the business. It involves extensive consultation with a range of stakeholders to develop the best solution that meets many potentially conflicting objectives: cost, function, consumer acceptability, transport efficiency, shelf presence, promotion and now sustainable development.

Build Sustainable Development into the Design Process

Designing for sustainability involves considering sustainability objectives as early as possible in, and regularly throughout, the design process. This provides the greatest potential to influence the design to achieve the best sustainability outcomes with least cost (see Fig. 2.1).

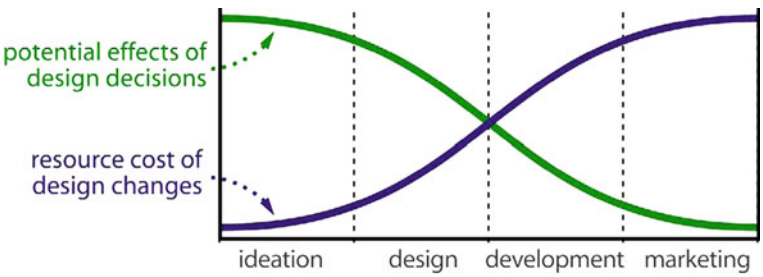


Fig. 2.1 The design approach. *Source*: McDonough Braungart Design Chemistry [96]

Sustainability Changes the Design Process

Sustainability in packaging design requires new information to be considered including:

- environmental life cycle of the product and its packaging
- the role of packaging in achieving sustainable development goals
- packaging environmental regulatory requirements
- systems in place for the recovery, use and disposal of packaging at end-of-life.

⇒ See Chaps. 4 and 5 to learn more about regulations and life cycle thinking respectively.

Increasingly, decision-support and eco-design tools are used to accelerate the integration and consistency of application of sustainable development into the design process. They also help educate the design team and relevant stakeholders on the impact of decisions on sustainability issues.

⇒ See Chap. 7 for more on applying tools to packaging design for sustainability.

2.2 Designing Packaging for Sustainability

Packaging is used for the containment, protection, handling, delivery, presentation, promotion and use of products. A number of packaging components make up the 'packaging system' (see Table 1.1) with each component selected for a particular purpose (see Table 2.1).

Aim to Create Economic, Social AND Environmental Value

Strategies to improve sustainable development, such as increased efficiency, recyclability and elimination of toxic components, must be balanced against all relevant performance criteria during production, distribution, storage and use [1]. The idea of 'balancing', however, implies trade-offs. While this is often necessary, the aim should be to design and manufacture packaging that simultaneously delivers economic, social and environmental value. This may require a departure from 'business as usual' to find 'win–win' solutions and new innovative ways of achieving the required objectives. Some examples of potential win–win solutions are provided in Table 2.2.

Commit to Innovation

Packaging development has a long history of technical innovation and enabling product innovation [2]. Examples include ready-to-eat fresh meals, re-sealable packs and longer-life packaging. These have taken advantage of advances in materials and food processing technologies and have sought to meet changing consumer tastes and lifestyle choices.

Table 2.1 Functions of packaging

Function	Features
Protection	Prevent breakage (mechanical protection)
	Prevent spoilage (barrier to moisture, gases, light, flavours and aromas)
	Prevent contamination, tampering and theft
	Increase shelf life
Promotion	Description of product
	List of ingredients
	Product features and benefits
	Promotional messages and branding
Information	Product identification
	Product preparation and usage
	Nutritional and storage data
	Safety warnings
	Contact information
	Opening instructions
	End-of-life management
Convenience	Product preparation and serving
	Product storage
	Portioning
Utilisation	Provision of consumer units
	Provision of retail and transport units
Handling	Transport from producer to retailer
	Point-of-sale display
Waste reduction	Enables centralisation processing and re-use of by-products
	Facilitates portioning and storage
	Increases shelf life
	Reduces transport energy

Source: EUROPEN and ECR Europe [91, p. 7]

Designing for sustainability requires a commitment to rethink the design of the product-packaging system. There are potential trade-offs between objectives, for example:

- material efficiency of a plastic pouch vs. the recyclability of a plastic bottle
- environmental benefits of enhanced recyclability vs. the cost of changing the packaging
- elimination of heavy metal-based inks or pigments vs. the marketing advantage of vibrant and durable colours.

However, approaches to the design process should begin by rethinking the problem in a more open and creative way. For example, can material efficiency AND recyclability be achieved by concentrating the product and selling it in a much smaller container? Does the recyclable package offer additional commercial or marketing benefits that justify the additional expense of the new design?

Table 2.2 Examples of 'win–win' packaging sustainability strategies

Design strategy	Cost	Functionality	Environment	Risks/potential impacts
Lightweighting	Reduced material costs Reduced transport costs	Easier for consumer to carry (i.e. less weight) Potential to improve openability/usability by simplifying the design (e.g. by removing unnecessary components)	Benefits throughout the life cycle due to avoided material production and waste Improved transport fuel efficiency (less material being distributed) and therefore less air emissions generated	Too much lightweighting can increase product damage and waste in the supply chain, which normally has higher impacts than the avoided packaging
Returnable transport packaging	Avoided costs of single-use packaging (The up-front costs of returnable packaging are higher than single-use packaging but a high return rate will generate cost savings) Avoided costs of baling and recycling single-use corrugated packaging	Potential to improve product protection (stronger containers)	Benefits throughout the life cycle due to avoided production and waste of single-use packaging (There will be some new impacts associated with cleaning and transport, and these need to be weighed against environmental benefits and minimised as much as possible)	Some new impacts associated with cleaning and transport that need to be weighed against environmental benefits and minimised as much as possible Up-front costs of returnable packaging are higher than single-use packaging but a high return rate will generate cost savings
Design for recycling	Simplification of the design may reduce packaging components and inventory costs (e.g. by reducing ink coverage or by eliminating labels)	Rethinking the design provides an opportunity to build in additional functionality.	Benefits throughout the life cycle due to avoided production (i.e. if virgin material is replaced with recycled material) Packaging material diverted from landfill	There may be increased costs associated with some recyclable materials

Use a Packaging Sustainability Framework

To integrate the new approaches required to address sustainability efficiently and effectively in packaging design, a packaging sustainability framework is useful as a decision-support tool. In this chapter we present and demonstrate the use of a framework that brings together traditional packaging design considerations with triple bottom line sustainability considerations. The framework is the latest evolution of work commenced by the Sustainable Packaging Alliance in 2002 [3]. It has been refined for this book in line with the evolution in thinking about packaging's role in sustainable development as outlined in Sect. 1.4.

⇒ See Sect. 1.2 in Chap. 1 to learn more about the triple bottom line.

The framework uses four principles to guide decisions about design, manufacturing, transport, use and recovery of packaging. Examples of strategies that can help to achieve these principles are provided together with a detailed case study demonstrating how to use the framework (see Appendix 1).

2.3 Packaging Sustainability Framework

In order to contribute to sustainable development, packaging needs to be (Fig. 2.2):

- *effective* in delivering the functional requirements of the packaging
- *efficient* in its use of materials, energy and water throughout its life cycle
- *cyclic* in its use of renewable materials and recoverability at end-of-life
- *safe* for people and the natural environment.

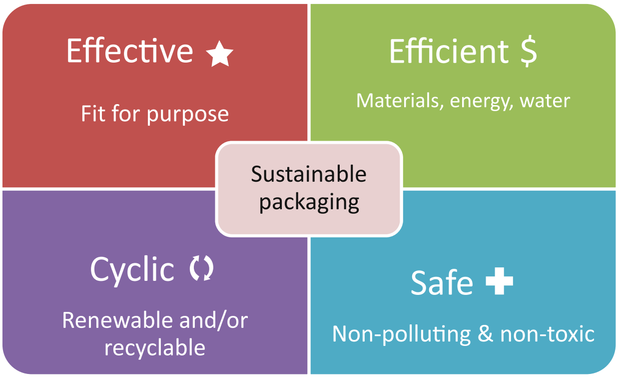


Fig. 2.2 The four sustainable packaging principles

Each principle is outlined in Sects. 2.3.1–2.3.4 respectively, and practical design strategies and case studies demonstrating their application are provided in Sect. 2. Section 8.2.8 also proposes metrics for aligning the design strategy with corporate sustainable development goals.

2.3.1 Effective Packaging

Effective ★

Fit for purpose

Effective packaging is fit for purpose and achieves its functional purpose with minimal environmental and social impact.

According to The Consumer Goods Forum [4, p. 11], well-designed packaging meets all its functional requirements while minimising the economic, environmental and social impacts of the product and its packaging. This reflects the concept of the triple bottom line and is a good definition of 'effective' packaging. Examples of the triple bottom line benefits of effective packaging are provided in Table 2.3.

Table 2.3 Potential triple bottom line benefits of effective packaging

Economic benefits	Reduced product damage Increased product sales Compliance (labelling)
Social benefits	Consumer convenience Accessible packaging (e.g. easy to open for older consumers)
Environmental benefits	Reduced production waste Reduced product damage in the supply chain

Demonstrate the Triple Bottom Line Benefits

The effectiveness principle requires designers to:

- demonstrate how the packaging design is 'fit for purpose'
- identify the economic, social and environmental value provided by the packaging
- re-examine conventional design objectives such as technical performance, convenience, cost and so on from a sustainability perspective.

⇒ The Sustainable Packaging Coalition guidelines [5] provide suggestions on rethinking conventional design criteria such as cost, technical performance, asset protection, etc.

Packaging must be Essential

Effective packaging fulfils a number of essential functions, such as [1, p. 10]:

- ensuring the contents are delivered to the consumer in good condition
- protecting the contents from hazards such as vibration, heat, odour, light penetration, micro-organisms and pest infestation
- being easy to open (but difficult to open accidentally) and pilfer-resistant
- allowing liquids to pour without spillage
- enabling all of the product to be dispensed
- being as easy as possible to carry
- for consumer goods, being attractive enough to buy
- providing information about the product, the business that bears responsibility for it, and instructions for handling or use.

The specific functional benefits of each component of the packaging system and the structure of the packaging system as a whole should be challenged and validated throughout the design process.

Explore New Opportunities

Businesses have always focused on the functional aspects of packaging design, but a focus on sustainability can open up new opportunities or a reassessment of the role of packaging. For example [5]:

- Are there opportunities to prevent theft in retail stores without relying on the packaging; for example, by modifying fixtures and displays?
- Is the package fit-for purpose but not over-engineered?
- Can the cost of the package be reduced through a more efficient design or by using materials that attract lower recycling fees (some countries have differential recycling fees—see Chap. 4 for more information)?

Applying the effectiveness principle should identify new opportunities for innovation including the creation of new product concepts that reduce the need for packaging (see The Keep Cup Case Study 2.1).

Case Study 2.1 The Keep Cup

The reusable ‘KeepCup’ for takeaway coffee demonstrates a new way of thinking for out-of-home packaging. Promoted as the ‘first barista standard reusable coffee cup’, the KeepCup has a similar shape to conventional coffee cups and is easily filled by a cafe espresso machine. Since its launch in 2009, over 1,000,000 of the cups have been sold in Australia, the United States and Europe. The product also highlights for consumers the production of waste associated with their purchase and consumption of takeaway beverages.

A streamlined life cycle assessment was used to compare the KeepCup with a conventional paper coffee cup. If both cups are used daily for 12 months, the KeepCup achieves a 97% reduction in global warming potential, a 98% reduction in water use and a 96% reduction in waste to landfill [6].

Photo: KeepCup

Design for Accessibility

'Design for accessibility' is becoming an essential design requirement for social sustainability. One of the most important access issues is ease of opening. Stringent requirements for packaging functions such as product protection, tamper evidence, and prevention of theft are often pursued at the expense of openability. Another accessibility issue is the ability of consumers with poor eyesight to read labels.

Design for accessibility has many implications for consumer health and safety including:

- packaging related injuries: many of these occur when people resort to a knife or scissors to open packages [7]
- inability to open packaging and thereby access products: consumers with functional disabilities associated with diseases such as arthritis sometimes cannot open packaging, and this problem is increasing as a result of the aging population in Western countries. Companies such as Duracell are redesigning packaging to address the needs of people with restricted strength or movement in their hands (see the Duracell Case Study 2.2)
- risk of product misuse: the poor readability of small text on labels is a problem—also arising from the aging population—and means that important information such as directions for use, safety warnings and disposal guidelines are sometimes not read.

Case Study 2.2 Design for Accessibility (Duracell)

In 2001, Duracell announced a new form of packaging to simplify the often difficult task of replacing hearing aid batteries. Batteries in the newer, more compact hearing aids are tiny, and wearers need to change their hearing aid batteries up to 50 times each year. The problem is magnified by poor eyesight and arthritis, which are common to many users. Duracell's EASYTAB™ packaging makes it easier to remove the batteries and insert them into the hearing aid.

Historically, hearing aid batteries were packaged in a circular case that required consumers to 'dial' a battery into an opening for removal. This allowed more than one battery to fall from the opening when the user shook it from the opening. If the batteries fell to the floor, particularly onto thick carpet, they were difficult to find. The batteries were packaged with a small tab that adhered to the battery to prevent exposure to oxygen before use. Removing this tab to activate the battery was very difficult for users with limited dexterity.

The new EASYTAB™ design features a brightly coloured tab attached to each battery, which is used as a tool to remove the battery and insert it in the hearing aid. If the battery is accidentally dropped, the tab is clearly visible. Once the battery is inside the hearing aid, the tab is removed to activate the battery.

Sources: Business Wire [8], The Center for Universal Design [9]

See Sect. 2.4.1 for a discussion and case study examples of design strategies for effective packaging.

2.3.2 Efficient Packaging

Efficient $

Materials, energy, water

'Efficient' packaging is designed to minimise resource consumption (materials, energy and water), wastes and emissions throughout its life cycle.

A common theme in the sustainable development literature is the need to go beyond incremental improvements and look for 'step changes' or significant improvements in eco-efficiency. For example, the authors of *Natural Capitalism* [10] have argued for 'radical' improvements in resource productivity to reduce depletion of resources and pollution and to lower costs'. Some researchers have estimated that for the world's resource use to be sustainable we need a 75–90% improvement in resource efficiency [11–13]. Examples of the triple bottom line benefits of efficient packaging are provided in Table 2.4.

Table 2.4 Potential triple bottom line benefits of efficient packaging

Economic benefits	Reduced resource costs—materials, energy, water
	Increased supply chain efficiency
	Cost savings passed on to consumers
Social benefits	More affordable products
	Reduced weight or volume
Environmental benefits	Reduced consumption of resources—materials, energy, water
	Reduced waste and emissions from production of virgin materials
	Reduced energy consumption and emissions from transport
	Reduced product waste

Apply Life Cycle Thinking

⇒ See Chap. 5 to learn more about life cycle thinking.

Life cycle assessment (LCA) studies show that minimising packaging and maximising supply chain efficiency are two of the three most important actions that reduce the environmental impacts of packaging [14]. (The other is use of renewable energy.)

As a general guide, reducing the weight of packaging by 20% will reduce environmental impacts of the packaging by about 20%. In contrast, recycling, while still desirable for many reasons, such as resource conservation, consumes energy and generates waste and emissions during transport and reprocessing [14].

Economic and Environment Win–Win

The benefits of more efficient packaging include:

- cost savings in the supply chain, which can be captured by the business or passed on to suppliers, customers and consumers
- less demand for materials, energy and water, which in some cases are being extracted from the natural environment at an unsustainable rate [15]
- less pollution and waste that must be absorbed by the natural environment by creating more efficient supply chains.

⇒ See Sect. 2 for strategies for designing for efficiency.

A number of businesses have adopted efficiency goals for packaging. Walmart, for example, plans to reduce packaging by 5% by 2013 compared to 2008 to reduce carbon dioxide emissions by 667,000 metric tons annually. This will also create US$10.98 billion in savings, including a US$3.4 billion saving to Walmart [16]. In 2008, Dell announced plans to reduce its packaging by 8.7 million pounds (3,946 tonnes), and by 2010 the company had already made significant progress (see Case Study 2.3).

Case Study 2.3 Efficient, Cyclic and Safe: Dell's Goals for Computer Packaging

In late 2008 Dell announced plans to eliminate 20 million pounds (9,072 tonnes) of packaging for its desktop and laptop computers by 2012 and to make the remainder of its packaging 'greener'. In the process, the company hoped to save an estimated $US8.1 million.

Dell's goals for packaging improvement are called the '3 Cs':

- cube—reduce the size
- content—use recycled or sustainable materials
- curb—ensure that it is easily recyclable.

These correspond to several of the sustainable packaging principles highlighted in this book, i.e. efficient, cyclic and safe packaging. In 2010 Dell reported a number of achievements, including:

- introduction of bamboo packaging for cushioning its Inspiron Mini 10 and 10v inside an outer box made from 25% post consumer materials
- elimination of 8.7 million pounds of packaging
- increased recyclability of packaging, with a shift to moulded pulp, high density polyethylene (HDPE) cushion, expanded polyethylene (EPE), bamboo and corrugate
- introduction of a 'multipack' for large orders that combines multiple orders into one box.

Sources: Greener Design [17], Dell [18]

See Sect. 2.4.2 for a discussion and case study examples of design strategies for efficient packaging.

2.3.3 Cyclic Packaging

Cyclic ()
Renewable and/or recyclable

'Cyclic' packaging is designed to maximise the recovery of materials, energy and water throughout its life cycle.

Match Materials with the Metabolic Cycle

⇒ See Sect. 1.2 to learn about biological and technical metabolisms.

As McDonough and Braungart state in their book *Cradle to cradle*, there is no waste in nature [19]. To minimise waste, packaging materials should be designed to become 'nutrients' for another process. Natural and renewable materials such as paper and wood should become nutrients for the biological metabolism; for example, in organic processes such as composting. Manufactured materials such as glass and plastics should become nutrients for the technical metabolism; for example, in industrial processes such as mechanical (material) recycling [19].

Examples of the triple bottom line benefits of cyclic packaging are provided in Table 2.5.

Table 2.5 Potential triple bottom line benefits of cyclic packaging

Economic benefits	Reduced material costs (recycled materials)
	Cost savings passed on to consumers
Social benefits	Reduced aesthetic impacts of litter
	Extension of life for existing landfills
Environmental benefits	Reduced consumption of resources—materials, energy, water
	Reduced waste and emissions from production of virgin materials
	Reduced packaging waste requiring disposal/recovery

Aim for Closed Loop Recycling

Closed loop recycling involves reprocessing materials back into the same application, e.g. packaging to packaging.
Down-cycling occurs when a material is reprocessed into an alternative, lower value application that often prevents further recycling, e.g. packaging into garden mulch.

It is generally more sustainable to recycle a material back into the same application (closed loop recycling) than down-cycle. A good example is a glass bottle, which can be re-melted in the glass furnace and manufactured back into a new bottle or jar.

⇒ Refer to Table 2.14 for recycling rates of common packaging materials globally.

Other materials are more difficult to reprocess back into the same application and may need to be 'down-cycled' into a lower value applications. For example, recycled plastic might not be suitable for the manufacture of new packaging because it does not meet food contact regulations, or it may not be able to compete with virgin resin because of the higher costs of processing. Therefore, it can only be down-cycled into products such as garden furniture and plant pots.

Design for recyclability aims to remove barriers to closed loop recycling to ensure that recovered materials can be reprocessed into high value applications. Some examples of closed loop material recycling and down-cycling (as well as barriers to them) are given in Table 2.6.

An emerging technology for the recovery of biodegradable plastic packaging is composting: a form of 'organic recycling'. These materials can potentially be

Table 2.6 Recycling options for common packaging materials

Material	Closed loop opportunities	Barriers to closed loop recycling	Examples of down-cycling opportunities
Polyethylene terephthalate (PET)	Jars or bottles, up to 100%	Quality (suitability for food contact), contamination with PVC	Fibre for clothing and other textile products
High density polyethylene (HDPE)	Bottles or tubs, up to 100%	The wide range of HDPE resins on the market, which may result in an inconsistent product, colour contamination	Crates, bollards, outdoor furniture, lumber
Polyvinyl chloride (PVC)	Bottles or tubs, up to 100%	Low cost of virgin resin, small quantity of post-consumer material	Pipe fittings, footwear, flooring
Glass	Jars or bottles, up to 100%	High cost of transport, contamination with ceramics/other glass, mixing of different coloured glass	Road base, asphalt, filtration media, blasting abrasive
Aluminium	Cans	Minimal	Car and truck components, doors, windows, siding
Steel	Cans	Minimal	Reinforcing rod, pipe, wire, appliances
Paper/cardboard	Boxes, cartons, bags	Quality of the recycled fibre (fibre length, colour, contamination)	Animal litter, insulation, mulch

collected in a source-separated organic stream (garden and/or food waste) for processing into organic products such as soil conditioner or mulch. Some of these materials may also be suitable for home composting.

⇒ See Chap. 6 to learn more about biodegradable materials.

Avoid Cross-Contamination Between Metabolisms

In Chap. 1 we introduced the work of McDonough and Braungart, who described two recovery mechanisms for products: the biological metabolism such as composting and technical metabolism such as an industrial recycling process. They argue that products should be designed for one of these metabolisms, and with care to ensure that a product designed for one system does not contaminate the other. Contamination could occur, for example, if a biodegradable plastic shopping bag, designed for composting, ends up in a conventional plastics recycling system, or if a polyethylene plastic bag ends up in a composting system.

One company that has carefully considered all of these issues is biscuit manufacturer Gingerbread Folk, which uses a biodegradable material certified to an international standard and advises consumers on appropriate disposal (see Case Study 2.4).

Case Study 2.4 Compostable Packaging: Gingerbreak Folk

Gingerbread Folk pack their biscuits in NatureFlex resin from Innovia Films. The raw material for the film is cellulose extracted from wood fibre. The label advises consumers that:

> 'We care about the planet, that's why the wrapper is compostable. When finished, please place this wrapper in your home compost—really, it is OK to do this'.

Photo: Gingerbread Folk

More Economic and Environmental Win–Wins

The benefits of recycling packaging often include significant environmental savings when recycled materials replace virgin materials in production. For example, it has been estimated that recycled aluminium requires only 7% of the energy required for virgin aluminium, and recycled high density polyethylene (HDPE) only requires 21% of the energy required for virgin HDPE [20, p. xi].

See Sect. 2.4.3 for discussion and case study examples of design strategies for cyclic packaging.

2.3.4 Safe Packaging

Safe ✚
Non-polluting & non-toxic

'Safe' packaging is designed to minimise health and safety risks to humans and ecosystems throughout its life cycle.

Designing for sustainability considers a broader range of potential impacts on the health of humans and ecosystems than traditional packaging design, such as:

- ecological impacts of growing natural raw materials, particularly from land degradation and biodiversity loss
- ecological and health impacts of pollution from manufacturing processes
- risks associated with migration of hazardous substances into food and beverages
- occupational health and safety risks in the supply chain
- impacts of packaging litter on wildlife, particularly in marine environments.

⇒ See Sect. 2.4.4 for strategies for designing for safety.

There are triple bottom line benefits of considering these impacts, as shown in Table 2.7.

Table 2.7 Potential triple bottom line benefits of safe packaging

Safe	
Economic benefits	Reduced costs of disposal (hazardous or toxic waste)
	Reduced risk of product recalls
	Carbon credits or reduced cost of carbon emissions
Social benefits	Reduced health and safety risks for consumers and neighbours
Environmental benefits	Reduced eco-toxicity impacts
	Reduced contribution to global warming

Take Responsibility for Sustainability Impacts of Raw Materials

Ecological and environmental stewardship are terms given to programs that aim to reduce the social and environmental impacts of farming, forestry or fishing practices.

Designing for safety must consider the environmental and social impacts of raw materials, particularly those derived from forestry or farming activities. This is often referred to as 'ecological stewardship'. Timber, fibre-based packaging materials and biopolymers from agricultural products can impact on biodiversity and the sustainability of natural ecosystems. Forestry operations, for example, may reduce or damage old growth forests. The procurement of 'renewable' materials needs to minimise any potential impacts; for example, by only using paper or cardboard from sustainably managed forests. Food security issues also need to be addressed; for example, by investigating the impact of diverting food crops such as corn to manufacture packaging. The Forest Stewardship Council (FSC) certifies materials according to ecological stewardship criteria, and businesses may specify only certified materials, as illustrated in the TetraPak Case Study 2.5.

Case Study 2.5 Forest Stewardship Council-Certified Cartons: Tetra Pak

Tetra Pak has been a member of the Swedish Forest Stewardship Council (FSC) since 2006, and their long term goal is to use FSC-certified fibre for all of their liquid food cartons. In September 2009, the company announced that beverage cartons with the FSC logo would be available to customers in Sweden, Denmark and Belgium. The cartons were already available in China, France, the United Kingdom and Germany.

FSC is an independent non-government organisation that promotes responsible management of the world's forests (more detail is provided in Sect. 2.4.4).

Source: Tetra Pak [21]

Implement and Support Cleaner Production Technologies

Cleaner production aims to reduce waste and emissions in manufacturing by changing management practices, processes and product design, rather than treating waste and emissions before disposal (the traditional 'end-of-pipe' solution).

Pollution from manufacturing processes in the packaging industry have a range of environmental and health impacts. Emissions of volatile organic compounds (VOCs) from printing processes contribute to ground-level ozone pollution, and the wastewater from chlorine bleaching of paper during the manufacturing process contains organochlorine compounds such as dioxins.

⇒ See Sect. 2.4.4 for more on chlorine bleaching of paper.

Designing for safety requires:

- understanding the processes used in manufacturing and printing packaging
- changing design specifications to shift to less polluting processes where available.

Validate Safety of Packaging

Food packaging systems must protect the integrity of the product so that consumer health is not compromised. Some constituents in packaging, such as Bisphenol A (BPA) and phthalates, can migrate in small amounts into food products. While there is scientific uncertainty about their health effects, there is mounting evidence that they are potentially toxic and should be avoided where possible [22]. A risk management approach to packaging safety requires:

⇒ See Sect. 2.4.4 for more on BPA and phthalates.

- understanding in detail the materials and constituents used in the packaging
- obtaining Materials Safety Data Sheets or other documentation from suppliers
- monitoring the latest published research on migration of substances into food and other consumer products
- consulting with suppliers, researchers and safety authorities if there are any concerns
- as a precautionary measure, taking steps to replace any materials or constituents that may pose a health risk.

Design for Safe Handling

The implications of packaging design for occupational health and safety in the packaging supply chain also need to be considered. For example, attention must be paid to any risks associated with storage and handling in the supply chain. Any packaging that requires a knife to open is a potential hazard to workers or consumers. Packaging should be designed for easy opening without the use of sharp instruments. The weight of packed products is also an issue, particularly for work that involves shifting or dispensing products. Weight is generally not an issue at the consumer level, although the larger capacity of reusable shopping bags often results in overloading, making the bags heavier and more difficult to handle by cashiers [23].

Design for Litter Reduction

Packaging litter has many sustainability impacts, including:

- injury or death of wildlife. It is estimated that 6.4 million tonnes of litter enter the oceans every year [24, p. 101]. While the impact of packaging is relatively small, a number of reports have highlighted wildlife impacts associated with packaging [25]
- damage to nautical equipment
- aesthetic impacts in waterways, along beaches and in other public places
- injuries to people; for example, cuts from broken glass
- costs of litter clean-ups.

The packaging design team can help to minimise the incidence or impact of litter; for example, by minimising the number of separable components or by communicating an anti-litter message. Litter statistics published by industry associations and/or non-government organisations can be used to better understand the products, packaging and brands that are littered most frequently. This information can then be used to see if any of the business's packaging portfolio falls within the most littered items.

See Sect. 2.4.4 for a discussion and case study examples of design strategies for safe packaging.

2.4 Applying the Packaging Sustainability Framework

In this section, design strategies and case studies are presented to illustrate how each of the four packaging for sustainability principles can be addressed:

- designing for effectiveness (see Sect. 2.4.1)
- designing for efficiency (see Sect. 2.4.2)
- designing for cyclic packaging (see Sect. 2.4.3)
- designing for safety (see Sect. 2.4.4).

⇒ See Chap. 8 for more on integrating sustainability in the product development process.

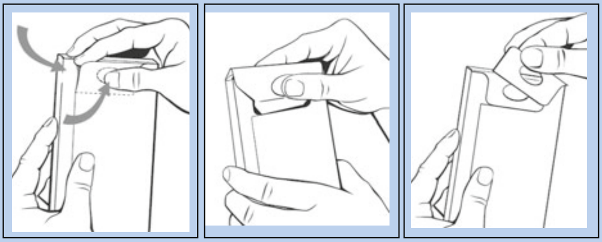
The packaging sustainability framework is a systematic approach to design that can be applied by assessing each of the four principles and the way they work together. It should be used particularly at the initial ideas stage of the product development process, where there is the most freedom to explore alternative strategies.

The design process should optimise the choice of projects in line with the business's sustainable development goals and metrics. In practice, the final design decision may require trade-offs to address competing goals and metrics. This is illustrated in the case study about Cadbury (Case Study 2.6) in which *more* material has been used to improve functionality and recyclability.

Case Study 2.6 Cadbury Dairy Milk Chocolate Bars

Cadbury Australia redesigned the packaging of its Dairy Milk chocolate bars in 2008, primarily to improve recyclability. The original packaging was made from a non-recyclable metallised paper. The new packaging consists of two recyclable components—an aluminium foil enclosed in a lightweight carton. While the overall weight of the primary packaging increased, market research found that consumers would be more likely to recycle a carton than the lighter weight alternative, a paper wrap. The redesign also provided an opportunity to introduce an innovative feature that allows the product to be resealed after opening, which is less messy and maintains the freshness of the product.

The new Dairy Milk packaging



Opening/reclose feature (patent pending)

Source: Chessell [26]
Images supplied by Cadbury Australia

2.4.1 *Designing for Effectiveness*

Effective ★

Fit for purpose

- Meeting consumer needs
- Functionality – technical performance, convenience, accessibility
- Opportunities for innovation

By focusing on the effectiveness principle the design team confirms:
- the role of each packaging component and the packaging system as a whole
- how the packaging protects the product and creates consumer value.

It may also help to generate ideas for new product-packaging concepts with the potential to deliver better value to the business and the consumer with less environmental impact.

Is the Packaging Necessary?

The first challenge is to enquire whether the package is necessary. In the process of answering this question, the design team gains a better understanding of the basic needs met by each package component and the packaging system as a whole [27, p. 21]. In some situations it may be possible to eliminate the package or a component of the packaging system that adds little or no value to the protection of the product.

Market research can be used to understand how and where a product is consumed and whether certain features of the packaging are actually required or used by customers and consumers. For example, fresh salad packaging often includes disposable cutlery because it is intended to be consumed away from home. It is therefore important to know where the salads are actually consumed and the extent to which the cutlery is used. If most salads are consumed at home or in a workplace, with ready access to durable cutlery, then this feature could potentially be removed, saving cost and environmental impact.

Optimise Function of all Components AND the System

Product containment and protection are the primary role of packaging. Depending on the product and its supply chain, the packaging system may need to protect its contents from:
- climatic influences, such as light, humidity and temperature
- mechanical hazards, such as impacts, accelerations, abrasions and vibrations
- gas and odour exchange
- contamination by micro-organisms or pest-infestation.

Secondary and tertiary packaging facilitates distribution by bundling products together for transport and handling. Secondary and tertiary packaging choices are inter-dependant with the primary packaging, and the complete system must be optimised.

From a sustainability perspective, it is important to ensure that all functional requirements are met without over-engineering the packaging system. Rethinking all of the technical requirements may open up new opportunities to reduce material or energy consumption or to improve productivity in the supply chain (see Case Study 2.7 on a hypothetical product).

Case Study 2.7 Rethinking Technical Requirements

A hypothetical food product has a 12 month shelf life, uses a film as the primary packaging and is packed in a display carton and then a corrugated case. The film provides a sufficient barrier to enable an 18-month shelf life without oxidation. The display carton is used for promotion by providing a shelf display. The corrugated case ensures the product survives national distribution.

Decide how many of the current (or new) product and distribution assumptions can be broken or challenged (e.g., shelf life, distribution modes). This is the hardest part, and sometimes requires looking at some different commercial environments. If your product is a typical supermarket product, look in a hardware store or a pharmacy for clues on how other products might be working.

Provided the product tastes as expected, and is relatively undamaged, the consumer is not particularly concerned about the display carton or corrugated case. Can these therefore be avoided? Could the shelf life be managed if it was shorter, say 10 months? This might allow a lower material gauge or less complex barrier film. The flow wrapper used to form the primary packaging might use a seal and end crimps. The consumer places no value on the size of these, so can they be removed to reduce the surface area of the primary packaging?

Is the display carton necessary, or is it only a method of 'bundling' a number of units? Could this be a bundling film wrap, or is that layer of the system necessary at all? Could the outer case count be reduced, removing the necessity for the display carton altogether?

With the corrugated case, could the distribution packaging be reduced? Does the business specify airbag suspension trucks? Are the maximum static and dynamic stack heights allowed really necessary? Truck height will typically allow a 2.4 m high stack, but do you produce 2 × 1,200 mm high, and line haul on rails? Do you fully utilise this height in the truck? Doing so may significantly reduce the impacts associated with trucking. Also, count

(continued)

Case Study 2.7 (continued)

only the surface area of the carton that you need to protect and contain the product. For example, a regular slotted carton generally has large areas of overlap in the closure flaps. This area does not add value to the protection and containment function of the case. It is there to allow manufacture of the box. Remove any surface area overlap that is not necessary from the calculations.

So, a possible packaging system for this product could consist of a lighter gauge film with no lost seal area, no display carton and a smaller count shipping case with a better pallet and truck space utilisation.

Source: Bryce Hedditch, SustainPak [28]

Design for Accessibility

Designing for 'accessibility' requires making packaging easy to open by the 'average' consumer as well as the elderly and consumers of any age with a disability or arthritis.

The openability of packaging can be promoted to consumers as a market differentiator. The Arthritis Foundation in the United States, for example, has developed an accreditation and labelling scheme for 'ease-of-use: user-friendly products and packaging' [29]. Like all design for sustainability strategies, openability can be easily addressed by integrating these requirements into the design process as early as possible (Table 2.8). Readability of labels by all consumers, including those with poor eyesight, also needs to be considered.

Table 2.8 Design for accessibility strategies

Cans with pull-tabs can be improved by deepening the pre-cut around the edge to make it easier to pull the lid up
Packages using a tear notch should indicate clearly and accurately where the notch actually is
Jars with rounded plastic lids and no serration should flatten the lids to a sharp edge and incorporate serration for grip
Foil lids should incorporate an opening tab that is big enough to grip
Screw-tops need to balance vacuum suction with how easy it is to open the product
Child safety and anti-tampering is of paramount importance but can be maintained by using intelligent opening systems such as lining up dots or arrows instead of 'squeeze in, push down and twist'
Reading instructions are imperative for safety reasons or efficacy, and design can be improved with these simple guidelines: • simple sans serif typefaces such as Arial or Helvetica are recommended for maximum readability • good contrast contributes to legibility. The text should be printed with the highest possible contrast • lower case text is easier to read, and using text consisting entirely of capital letters should be avoided.

Source: Judith Nguyen from Arthritis Australia, cited in Packaging News [92]

2.4.2 Designing for Efficiency

Efficient $

Materials, energy, water

- Material efficiency
- Minimising product waste
- Energy efficiency

By focusing on the efficiency principle the design team confirms:

- the amounts of packaging used and required
- the environmental benefits provided by the packaging through product protection
- the life cycle environmental impacts of the packaging components and system arising from energy consumption.

Right-sizing is reducing the size or weight of the package but not to the point at which the product becomes vulnerable to breakage or spoilage [27, p. 36].

Is the Packaging Necessary?

The first step in efficient design is to identify any components of the packaging system that are not necessary and could be eliminated (see Case Study 2.8 on Sainsbury's). This step should be taken when first considering design for effectiveness. A proper assessment of efficiency considers the interaction between all components of the packaging system throughout the distribution chain and looks for any that can be eliminated, keeping in mind that a reduction in the weight of a primary pack may require stronger secondary packaging or result in more product damage. This is why packaging needs to be *optimised* rather than minimised.

Case Study 2.8 Eliminating Packaging at Sainsbury's

Sainsbury's in the United Kingdom has announced that its 'basics' range of cereals will be stocked in plastic bags rather than a bag inside a carton. When fully implemented across the product range, this will result in 165 tonnes less packaging per year.

Source: Ditching Cereal Boxes [30]

Opportunities to Minimise Material Use

Packaging should be manufactured with the minimum amount of material required to be effective. There is significant room to reduce material use in packaging: a European evaluation of packaging efficiency for 468 common products found that on average, the product contributed 80% of the weight of the packed pallet but only 50% of the volume [31, p. 7]. A Dutch study concluded that the most significant environmental gains for packaging can be made by choosing smaller-sized packaging and/or a more easily stackable shape [32]. Both strategies allow more products to be packed in a container or truck, reducing the cost and environmental impact of transport. Metrics used to measure changes in material use include packaging weight, packaging-product ratio and cube utilisation (a volumetric measurement of packaging design efficiency). See Case Study 2.9 where Bunnings made improvements to a hardware product.

Case Study 2.9 Materials Efficiency: Bunnings

Bunnings is Australia and New Zealand's leading retailer of home improvement and outdoor living products and a major supplier of building materials with 239 stores and more than 30,000 employees. As part of its wider commitment to environmental sustainability, the company is implementing a range of energy and water efficiency and waste minimisation initiatives. In terms of packaging these have included the elimination of single-use plastic bags (action in Australia commenced in 2003) and the introduction of recycling programs for packaging received in store. During 2008/2009 Bunnings' recycling rates doubled for the second consecutive year from 25 to 50%.

In 2008 the company engaged consulting group Net Balance to undertake an audit of product packaging to review its environmental performance. The audit found many examples of efficient or recyclable packaging but it also identified numerous examples of 'over-packaging'. For example, some electrical extension leads were packed individually in plastic bags while others were sold with only a sales tag providing essential information and a bar code. Many products sold in hardware stores require very little protection and in these cases there is an opportunity to eliminate or reduce packaging. In addition to its impact on resource consumption and waste to landfill, unnecessary packaging adds costs to the business. These include:

- the hidden costs of packaging in the product
- opportunity costs—it takes up additional shelf space and reduces the ability of the business to keep stock on hand
- staff unpacking and re-packing time
- disposal costs.

The recommendations of the audit have been implemented through ongoing work with suppliers to reduce unnecessary packaging. A Working

(continued)

Case Study 2.9 (continued)

Group was established with the company's 10 largest local suppliers, and as a result sustainable packaging principles were integrated into packaging specifications for imported products. Bunnings continues to work toward reducing unnecessary packaging in keeping with its long term strategy to reduce waste to landfill.

An early example of a packaging improvement is shown below.


Old packaging

New packaging

These wrenches used to be individually wrapped in plastic film and then unitised in a flexible PVC bag. They now have minimal packaging—a product cable to hold the wrenches together and a swing tag.

Sources: Bransgrove [33], Bunnings Group Limited [34]

Photos: Bunnings

Reduce Packaging Weight

The next step is to identify opportunities to reduce the size or weight of all packaging components (Table 2.9).

Optimise the Product-Packaging System: Avoid Under-Packaging

⇒ See Chap. 5 for more on LCA.

Understanding the product environmental lifecycle and the role of packaging allows an assessment of whether a product is 'under-packaged'. This is particularly important, as the environmental impact of products may be many times that of the packaging (see Sect. 1.1). It has been estimated that the energy required to make food packaging, for example, is approximately 10% of the energy used to produce, protect, distribute, store and prepare the food it contains (Fig. 2.3) [35, p. 4].[1]

[1] The percentage is higher for some products, e.g. 16% for cereals, 23% for fresh fruit, 20% for fruit produce, 28% for alcohol, 23% for snack foods and 46% for soft drinks [35].

Table 2.9 Strategies to improve materials efficiency

Down-gauge (in thickness and weight) as much as possible
Eliminate unnecessary void space, layers and components
Eliminate labels by printing directly onto the packaging
Optimise the quantity of product in the consumer package to meet the needs of the consumer while also, wherever possible, reducing the packaging-product ratio
Consider using a larger volume pack, although it is important to ensure that this does not result in more product waste
Increase the volume density by concentrating products such as juice, soups and detergents
Design lightweight refill packs
Strengthen or weaken certain components to reduce overall material use
Minimise use of inks where this will not compromise the consumer appeal of consumer units
Ensure primary packs fit snugly into secondary units
Optimise secondary packaging dimensions to ensure good pallet optimisation
Use point-of-sale displays to convey messages and image rather than increasing the packaging on every item
Investigate whether plastic slip-sheets can be used instead of pallets
Investigate the potential to replace secondary packaging with a bulk reusable transit packaging system
Review competitors' products and international best practice to identify new design or lightweighting options

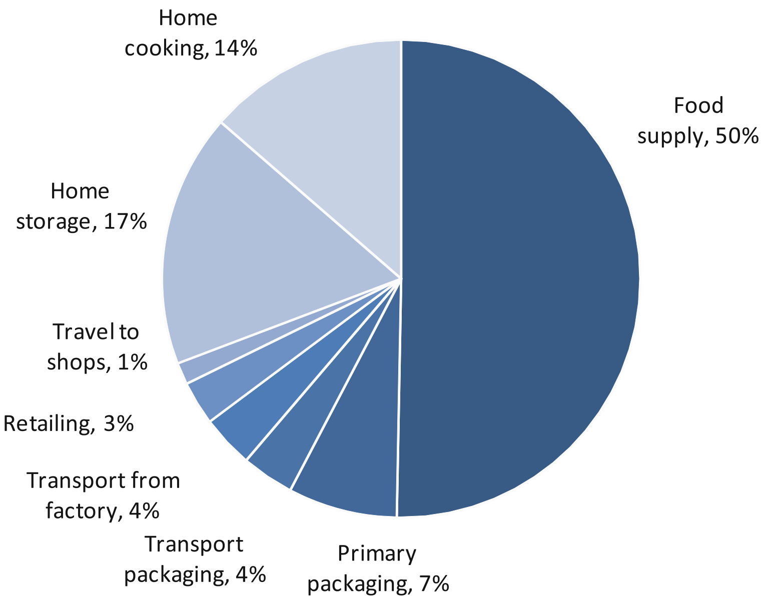


Fig. 2.3 Energy for one person's weekly consumption of food. *Source*: Based on INCPEN [35, p. 4]

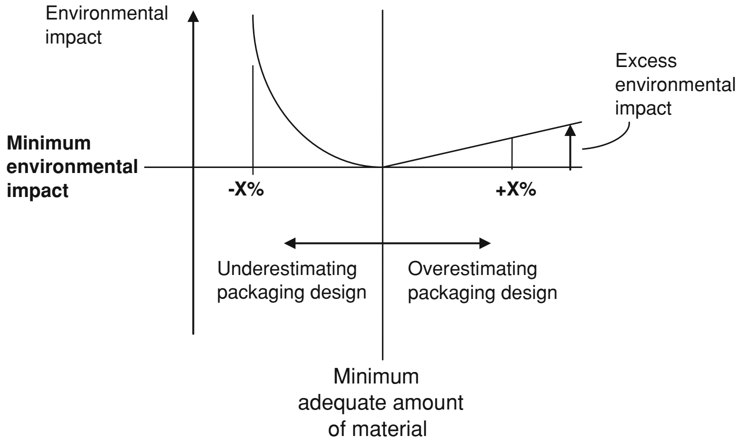


Fig. 2.4 Comparing the impacts of over-packaging and under-packaging. *Source*: Based on Erlov et al. [36, p. 4]

A model developed by Packforsk (Fig. 2.4) compares the environmental consequences of underestimating and overestimating the amount of packaging required for a product [36]. The growth in environmental impact that results from over-packaging is linear. However, the growth in environmental impact that results from under-packaging is exponential because it is linked to the impact of the packaging as well as the lost product. Over-packaging by 10% means that 10% of the resources needed to produce and transport the packaging are unnecessary and therefore wasted. Under-packaging may result in packaging failure, which usually leads to 100% waste of the resources used to produce and distribute both the product and its packaging [1, p. 11].

Sometimes less packaging can reduce rather than increase the amount of product waste. This has occurred with the redesign of distribution packaging for appliances and electrical equipment from corrugated boxes to clear film. While film is not as strong as a box, material handling workers tend to be more careful because the product is visible and damage cannot be concealed. The result is less product damage and waste in the supply chain [37].

Redesign the Product

There may be an opportunity to redesign the product to reduce packaging consumption and transport impacts. Examples include concentrated detergents (Case Study 2.10) and ‘flat packaged’ furniture.

Case Study 2.10 Redesigning the Product: Laundry Detergent

Unilever has shifted to more concentrated liquid detergents that require less packaging and are more efficient to transport. In Australia, for example, the introduction of concentrated Omo and Surf 'Small & Mighty' detergents, and the associated switch from 1.4 L to 475 mL bottles, resulted in:

- a reduction of 82 tonnes of plastics per year
- 32 tonnes less material in landfill
- environmental savings from materials use, manufacturing, transport, and recycling.

In 2008 it won the Packaging Council of Australia (PCA) Sustainability Award.

Photo: Helen Lewis

Sources: Unilever [38], Packaging Council of Australia [39]

Optimise the Product-Packaging System: Dispense ALL the Product

Efficient packaging design ensures that the product-packaging system is designed to allow complete dispensing of the product.

Any product residue left behind in the packaging when it is disposed in a recycling or rubbish bin represents an environmental and financial cost associated with poor packaging design. The resources consumed and environmental impacts arising from the production of inputs and the product are often higher than those associated with the packaging itself (see Sect. 1.1). The lost product is a financial cost to the consumer, who has paid for a product that cannot be fully consumed.

Strategies to help ensure that packaging can be fully emptied include:

- designing bottles with a wide neck
- using perforations that allow cartons to be opened all the way across the top
- selecting appropriate materials
- modifying the rheological properties (flow) of the product
- using packs that can be stored inverted—with the opening at the bottom.

Reduce Energy Consumption

Efficient design aims to reduce energy consumption at every stage of the product environmental life cycle to help conserve fossil fuels and reduce greenhouse gas emissions.

There are many strategies that can be used to minimise energy consumption throughout the supply chain, including optimising the design of all packaging components for transport efficiency. The selection of materials is also important, because some materials have lower 'embodied energy' than others; that is, they use less energy in raw materials extraction and manufacturing processes. For each material type, a lighter weight pack will also use less energy than a heavier one to manufacture and transport.

Energy efficiency strategies are presented in Table 2.10 and in the Superior Dairy Case Study 2.11, energy benefits of the square milk bottle.

Table 2.10 Energy efficiency strategies

During production
• Minimise the amount of material used, for example through lightweighting (see Table 2.9)
• Select materials that are more energy efficient; i.e. that have relatively low 'embodied energy'
• Maximise the amount of recycled content (recycled material uses significantly less energy—see Table 2.13)
• Purchase materials from suppliers with an effective energy efficiency program (e.g. ask for data on energy consumed to generate a unit of product)
During transport
• Reduce the size of packaging; for example, by concentrating the product or reducing void space, to increase pallet utilisation and therefore reduce the number of truck movements
• Switch to bulk distribution of raw materials and components to increase the amount of product being carried on each truck and therefore reduce the number of truck movements
• Reduce the weight of packaging to reduce fuel consumption
During consumption
• Provide clear and prominent information for consumers on whether or not refrigeration is required (some consumers refrigerate products unnecessarily; e.g. some spreads and sauces)
• Provide clear and prominent information on energy-efficiency; e.g. labelling on laundry detergents should promote minimum doses (to reduce overall use of detergents) and cold-water washing (to reduce energy consumption in appliances)
• Use long life packaging for products to eliminate the need for refrigeration in transport; e.g. aseptic packaging

2.4.3 Designing Cyclic Packaging

- Renewable materials and energy
- Design for reuse
- Design for recycling
- Recycled materials

Case Study 2.11 Energy Efficiency: The Square Milk Bottle

Photo: Helen Lewis

In 1998 Superior Dairy in Canton, Ohio, redesigned the conventional gallon milk bottle to eliminate the need for milk crates. Milk bottles are normally transported in plastic milk crates that can be stacked for transport. The crates require a lot of material to manufacture and need to be loaded, unloaded, collected, shipped back to the dairy empty, washed, stored and replaced when lost or stolen—a common problem for the highly functional milk crate.

Through their sister company, Creative Edge, the dairy undertook a major redesign of the milk bottle to make it self-stacking. The bottle has a square shape, slightly thicker walls and a recessed spout. These design features allow the bottles to be stacked six-high on a pallet.

Walmart picked up the innovative bottle design in 2008 for their own brand 'Member's Mark' milk, which is sold in their discount store Sam's Club. When the product was launched, Sam's Club reported that the trucks used for shipping can accommodate approximately 9% more milk: 4,704 gallons per truck or approximately 384 more bottles. This results in a significant saving in energy and greenhouse gas emissions associated with transport from the dairy to the retailer, and a cost saving for Walmart. A percentage of the cost saving is being passed on to consumers.

Sources: Sam's Club square case-less milk jug packaging [40], Mans [41]

By focusing on the cyclic principle the design team confirms how to:

- reduce consumption of virgin materials
- reduce reliance on non-renewable resources
- maximise the recovery of packaging materials.

A renewable resource is a natural resource that is depleted at a rate slower than the rate at which it regenerates. Packaging materials that are theoretically 'renewable' include wood, paper and some biodegradable polymers (those made from natural products such as corn or cellulose).

Reassess Reusable/Refillable Consumer Packaging

Most packaging was originally reusable or refillable, particularly for beverages. However, in most developed countries reusable glass bottles have been replaced by single-use containers. There are a number of reasons for this shift:

- the introduction of self-service supermarkets and the decline of home delivery services
- industry consolidation to achieve economies of scale and the increasing size of distribution networks, particularly international networks, which add to transport costs for the return of empty bottles
- an increase in the proportion of beverages consumed away from home
- a decline in return rates for refillable bottles, which reduced their financial viability and environmental benefits
- the opposition of brand owners and retailers to reusable packaging for a range of commercial, health and safety reasons.

This shift has been less pronounced in countries with specific regulatory measures in place to encourage reusable packaging. In Germany, for example, there is an industry cooperative that supplies refillable glass and PET bottles to over 230 mineral water bottlers [42, p. 212]. The users of this system tend to be small businesses, and the bottled water is generally only transported a few kilometres. In Norway, refillable soft drink containers have a market share of approximately 98%, and their market share for beer is around 44% [42, p. 213].

Self-dispensing systems are common in specialty organic or health stores, where customers are encouraged to bring their own packaging to the store for filling. Recent developments in the United Kingdom indicate that retailers and manufacturers may be willing to introduce refill systems for mainstream products. UK-based organisation WRAP (Waste & Resources Action Programme) has undertaken research on the potential for these to be introduced for beverages in retail stores [43], and in 2009 and 2010 funded a self-dispensing trial for liquid laundry products [44]. This research will be important in determining whether refillable packaging should be reconsidered for some mainstream consumer applications.

Identify Supply Chain Packaging Reuse Strategies

In contrast to consumer packaging, the reuse of secondary and industrial packaging has increased over the past decade [42]. Reusable systems include plastic trays and crates, intermediate bulk containers, wooden or plastic pallets, beer kegs, roll cages and moulded plastic containers for specialty products (see Case Study 2.12 and 2.13).

Case Study 2.12 CHEP Reusable Crates

An LCA compared a returnable plastic crate with single-use corrugated packaging (100% recycled content) for transporting fresh produce from farm to retail store. The study concluded that the crate generated 70% less greenhouse gas emissions, 95% less solid waste and used 85% less water. According to CHEP their returnable crate system also delivers increased functionality and financial value in the supply chain.

Photo: CHEP

Sources: CHEP [45], Crates Offer Produce a Green Premium [46]

Case Study 2.13 Reusable Kitchen Worktop Packaging

WRAP and home improvement retailer B&Q assessed the feasibility of a reusable packaging system for kitchen worktops. Worktops require a significant amount of packaging to avoid transit damage and scuffing of worktop corners, edges and presentation surfaces. Any damage can result in the product being rejected by the customer and then scrapped.

Single-use cardboard packaging was replaced in a trial with a purpose-designed, reusable plastic 'Carrierpac' (45% recycled content and recyclable at end-of-life). The Carrierpac was found to be quicker to pack and unpack,

(continued)

Case Study 2.13 (continued)

and there were no reports of product damage (eliminated product losses and increased customer satisfaction).

The Carrierpac was adopted by B&Q, reducing annual packaging use by 1,100 tonnes and damage rates from 6% to less than 1% (saving 900 tonnes of worktops from landfill per year), and saving B&Q £1m per annum. Since the launch, some Carrierpacs have reached 80 reuses, with average reuse now running at over 40 trips. If adopted by other leading manufacturers and retailers it could reduce waste by over 5,000 tonnes per year.

Photo: WRAP and B&Q

Source: WRAP [48]

If used appropriately, reusable transport packaging may generate a range of sustainability benefits [48, p. 2]:

- *cost savings*—reduced packaging and waste disposal costs, reduced product damage and reduced cost of returns and rejects
- *consumer benefits*—increased satisfaction, no bulky waste to recycle or dispose of and improved product presentation
- *company and employee benefits*—reduced risk of personal injury to packing and delivery teams, improved customer service, improved company image, and marketing opportunities
- *environmental benefits*—less packaging waste and reduced product damage.

PIRA International has undertaken a detailed analysis of the costs, benefits and feasibility of multi-trip boxes and crates used to transport products between the packer and retailer, which are becoming widely used in some sectors [49]. They concluded that reuse systems are not always appropriate as an alternative to the conventional shrink wrap and corrugated packaging systems, depending on a range of factors including distribution costs, size and shape of the primary pack, branding, susceptibility to damage, product turnaround, supply chain, the level of

Table 2.11 Suitability of products for returnable packaging

Returnable transport packaging	Non-returnable packaging
Loose product	Highly branded product
Certain bagged product	Products with high distribution costs
Easily damaged product	Imported product
Manually packed product	Large items
Fast turnaround, closed loop product	Products produced and packed on high speed packaging lines

Sources: PIRA [49], Saphire [50]

Table 2.12 Strategies for reusable secondary or tertiary packaging

To optimise its environmental performance, reusable packaging should: • be durable and designed for easy maintenance including cleaning • be collapsible and/or nest-able to optimise return transport capabilities • be as lightweight as possible • incorporate recycled content where possible • have facilities available for cleaning, repair or reconditioning • be recyclable at end-of-life

automation and transport distances. Accordingly, some sectors appear to benefit most from reusable transport packaging systems (Table 2.11).

Saphire [50] found that reusable transport packaging is more likely to be feasible under the following circumstances:

- short distribution distances
- frequent deliveries
- a small number of parties
- company-owned vehicles.

These conditions are most likely to exist in closed loop distribution systems where the container always goes back to the same point of origin.

Many companies use standard off-the-shelf pallets, crates, boxes, drums and intermediate bulk containers to transport products, components and raw materials. In other cases, reusable packaging needs to be designed to meet specific needs and to minimise environmental impacts (see Table 2.12).

Use of Recycled Materials

Every attempt should be made to maximise the use of materials with recycled content as they:

- generally consume less energy to manufacture (see Table 2.13)
- reduce consumption of virgin material and reliance on non-renewable resources
- often generate less pollution and greenhouse gas emissions because they avoid the manufacture of virgin materials.

In some cases recycled material may also offer a cost advantage.

Table 2.13 Energy savings from the use of recycled rather than virgin material

Material	Energy saving from use of recycled material (%)
Corrugated board—unbleached	22
Steel	79
Aluminium	93
HDPE	79
PET	76
PVC	80
Glass	57

Source: Grant et al. [20, p. xi]

⇒ Food contact regulations are discussed in Chap. 4.

The use of materials with recycled content may be limited by:

- the function of the packaging or packaged product
- supply constraints
- health and safety standards.

Recycled polymers can only be used in direct food contact applications if they meet stringent safety standards. The exception is non-processed fruit and vegetables. In other applications the recycled polymer needs to be certified by the appropriate food safety authority. The test standard that is often applied is the US Food and Drug Administration's (FDA) standard for recycled materials in direct food contact [51]. Recycled resins that meet the FDA standard have either undergone a feedstock (chemical) recycling process or a 'super clean' mechanical process involving several cleaning and decontamination stages. Multilayer co-injection techniques, which provide a functional barrier between the recycled resin and the contents of the container, are more expensive and have largely been replaced by monolayer processes.

Recycled PET (rPET) is generally blended with virgin resin at rates of up to 50% in order to meet the strict technical and aesthetic requirements for food grade packaging. It is increasingly being used for primary packaging; for example:

- A percentage of rPET is used in Coca Cola bottles in the United States, Netherlands, Belgium, Switzerland, Germany, Sweden, Australia, Japan and Mexico, and an extensive trial in the United Kingdom established that it can be combined with virgin resin at rates of up to 50% [52]
- In 2007 McDonald's Australia replaced its virgin polystyrene dessert cups with PET cups containing 35% recycled content [53]
- Direct Pack Inc. in collaboration with Global PET began production of its 100% rPET takeaway food containers ('The Bottle Box') in California in 2009 [54].

A large scale trial of recycled rPET in retail packaging was undertaken by WRAP in the United Kingdom between 2004 and 2006 [55]. As part of this trial, a percentage of recycled resin was incorporated in a selection of Marks & Spencer's takeaway salad bowls (50%) and juice bottles (30%), and Boots' toiletry bottles (30%). The trial demonstrated that rPET could be successfully incorporated within the containers, and both companies expressed their willingness to continue rolling out the use of rPET across additional lines. More detail is provided in the case study on Marks & Spencer's 'food to go' range below (Case Study 2.14).

Case Study 2.14 Recycled PET (rPET) in Marks and Spencer's 'Food to Go' Range

In June 2005 Marks & Spencer announced the launch of its rPET range of packaging to coincide with the re-launch of their 'Food to Go' range of food and beverage products. Market research into customers' perceptions about Marks & Spencer's packaging highlighted some concerns about rigid plastics and polystyrene. In response, the company developed a range of sustainable packaging initiatives including the use of rPET in a range of 'to go' packaging lines. The initial trial was undertaken with the support of WRAP and Closed Loop London between August 2004 and February 2006.

The target percentage of recycled resin was based on the level that was considered technically and aesthetically feasible as well as the need to include a 'meaningful' percentage rather than a 'tokenistic attempt to appear to be offering a greener packaging solution' [55, p. 54]. As a result of these considerations, the decision was taken to incorporate 50% rPET in the thermo-formed sheet used to make salad bowls and 30% rPET for blow moulded juice and 'smoothie' bottles. The containers were labelled with a 'closed loop' recycling symbol and the words '50% recycled content' and '100% recyclable'. Collection bins were provided in some stores to collect packaging labelled with the 'closed loop' symbol, including the PET containers and paperboard sandwich packs.

Results were as follows:

- The recycled product was safe, meeting regulatory requirements for plastics in contact with food
- There were no problems with material clarity and colour
- The rPET was able to be processed on existing equipment with only minor changes to the equipment used to manufacture the bottles. There was no impact on production efficiency
- Raw material costs were comparable or slightly better than for virgin PET
- There was continuity of supply for the recycled material
- Customer feedback was very positive.

An important finding was the need to closely specify material standards for the rPET to ensure that high quality standards were achieved for the packaging.

(continued)

Case Study 2.14 (continued)

The next stage of the roll out was expected to incorporate rPET in additional lines, including more juice and smoothie bottles, flavoured milk bottles, pre-prepared fruit salad trays, dessert pots and prepared vegetable trays and boxes.

Sources: Churchwood et al. [55], Marks & Spencer [56]

Recycled PET is also used to make bottles for detergents and other household products, although in these applications PET competes with PVC and HDPE. For this reason the market is highly price sensitive.

Recycled HDPE is widely used to manufacture bottles for non-food products, such as detergents, bleach and other household chemicals. It is very rarely used for food and beverage packaging, but Marks & Spencer's organic milk bottles are now manufactured from a blend of recycled HDPE resin certified to the FDA standard (10%) and virgin HDPE [57]. Post-consumer HDPE is also blended with LDPE or LLDPE to produce films for carry bags and rubbish bags.

Recycled paper and cartonboard can be used for some food-contact packaging as long as the sources of the fibre are known (some sources are not acceptable, such as paper from mixed waste) and the recycled material has been processed and cleaned to a level that meets all food safety requirements. Swiss researchers have found traces of mineral oils in recycled cartons at unacceptably high levels [58]. The oils are from printing inks in newsprint, which cannot be removed completely during the recycling process. One solution is to pack foodstuffs that are especially susceptible to mineral oil migration in an inner liner bag [58]. Another is to improve the efficiency of the recycling process to improve the removal of mineral oils. Recycled fibre can be used in secondary packaging or in the inside liners of multi-wall corrugated paperboard (for example, a double or triple wall). These components can be manufactured from 100% recycled fibre without seriously affecting performance.

⇒ Detailed guidelines on the use of recycled content in plastics packaging are available from the Sustainable Packaging Coalition [59].

A high level of recycled content may require an increase in board weight (see Case Study 2.15). These types of trade-offs need to be considered by the design team in the context of the business's overall corporate and sustainable development goals and metrics (see Chap. 8).

To optimise the use of recycled material in packaging, it's necessary to [5]:

- determine whether the technical requirements of the packaging can be met using recycled material, and if so how much can be used
- find suppliers with dependable sources of recycled materials that meet the business's packaging requirements
- set internal goals for the use of recycled material.

Case Study 2.15 Source Reduction Versus Recycled Content Paperboard

As a general rule, source reduction (e.g. through lightweighting) is preferable to recycling. Recycled materials have a lower environmental impact against most indicators than the equivalent virgin material (see Table 2.13), but using less material in the first place has an even lower impact.

For folding cartons, using 100% recycled paperboard may require a slight increase in the weight of the packaging compared to solid bleached sulphate (SBS) or coated unbleached kraft (CUK). This example provides an exception to the rule that source reduction is always preferable because the environmental impact for recycled paperboard is substantially less than the environmental impact for virgin board on a weight-for-weight basis. The recycled board is environmentally preferable even if the carton is 10–20% heavier.

A smaller percentage of recycled fibre (20–30%) can be added to SBS or CUK board without increasing its weight.

Source: The Paper Task Force [60, pp. 100–101]

Design for Mechanical Recycling

Recyclable means: ‘a characteristic of a product, packaging or associated component that can be diverted from the waste stream through available processes and programs and can be collected, processed and returned to use in the form of raw materials or products’ [61, p. 13].

The recyclability of a packaging material depends on two things:

- its technical recyclability: the ease with which it can be reprocessed and used to manufacture new products
- the availability of collection, sorting and reprocessing facilities for the material.

⇒ Consult with material recovery facility (MRF) operators and recyclers on the recyclability of any new packaging system, particularly if it uses a combination of materials.

A systems approach is therefore required; one that considers both the design of the package and the availability of a recovery system. A material may be *technically* recyclable, but if material recovery facilities (MRFs) and recyclers do not have the technology to separate and reprocess it, or if there is no viable end-market for the material, then it is effectively non-recyclable (see Fig. 6.2 for a description of MRFs).

⇒ More detail on the recyclability of individual materials is provided in Chap. 6.

Technical recyclability depends on the characteristics of the material itself as well as recycling technologies. As new technologies are developed and become commercially available, more materials are likely to be considered ‘recyclable’.

Recyclability also depends on the availability of recovery and recycling services, which vary by geographic region (Table 2.14). The packaging materials most widely collected through kerbside and ‘drop-off’ services are glass

Table 2.14 Packaging material recycling rates by geographical region (%)

Country	Glass	Paper and paperboard	Plastics	Steel	Aluminium	Total metals	Wood	Total
European Union	64	77	28	NA	NA	67	41	59
Austria	86	84	33	NA	NA	67	19	67
Belgium	100	92	38	NA	NA	91	72	80
Bulgaria	71	98	20	NA	NA	0	0	55
Cyprus	10	39	14	NA	NA	70	22	26
Czech Republic	65	94	46	61	31	56	37	66
Denmark	128	61	22	NA	NA	87	33	57
Germany	84	80	43	91	74	90	30	67
Estonia	62	57	38	NA	NA	18	39	50
Finland	81	88	18	NA	NA	70	10	52
France	62	89	21	57	40	64	21	57
Greece	18	80	14	54	34	51	75	48
Hungary	21	87	17	NA	NA	65	20	46
Italy	60	70	28	59	54	67	54	57
Ireland	76	77	22	NA	NA	68	76	61
Latvia	35	58	23	NA	NA	50	24	40
Liechtenstein	63	77	3	100	100	100	0	88
Lithuania	36	68	29	NA	NA	57	32	43
Luxembourg	92	71	39	NA	NA	80	31	63
Netherlands	81	74	26	NA	NA	84	32	61
Norway	99	82	30	66	NA	66	NA	68
Poland	40	69	28	21	82	30	48	48
Portugal	46	82	15	NA	NA	63	71	57
Romania	17	61	15	NA	NA	55	9	31
Slovakia	55	86	42	NA	NA	74	5	61
Spain	56	61	23	NA	NA	63	61	52
Sweden	95	74	42	77	69	74	17	59
United Kingdom	55	79	23	56	31	52	77	59
Australia	46	65	31	38	70	49	NA	56
Japan	NA	61	NA	88	91	NA	NA	NA
Korea	72	69	NA	NA	NA	NA	NA	NA
New Zealand	62	78	23	47	88	NA	NA	60
United States	28	62	12	65	39	NA	15	43

Notes NA not available. Rates are calculated as material recycling as a percentage of material consumption, although the methodology for data collection varies between countries. *Sources* Europe (2007) [93]; Australia (2007) [94, p. 6]; US (2007) [95, p. 7]; New Zealand (2007) [97]; Japan (2006) [98, pp. 73, 74, 79]; Korea [99, pp. 25–26] (2004) containers, aluminium and steel cans, selected plastic containers (often PET; sometimes other plastics), paper bags, cartons and corrugated boxes. Milk and juice cartons (liquid paperboard) are also collected in some areas.

Recyclable packaging is generally collected as a mixed (commingled) stream and then sorted at a MRF, although sometimes individual materials, particularly paper and paperboard, are collected separately. At the MRF, individual materials are sorted and compressed or baled for transport to reprocessors, who then use these materials to manufacture new raw materials or products.

⇒ Detailed guidelines for specific materials have been published by the Packaging Resources Action Group [62] and Recoup [63].

The use of multiple materials can inhibit recycling or cause problems in the recycling process. For example, plastic 'windows' on pasta boxes, plastic film on tissue boxes and the moulded plastic on blister packs are separated in the paper recycling process but will end up in the waste stream. Plastic or wax coatings on paper also reduce the amount of fibre that can be reclaimed. An example of a business working to improve the recyclability of its packaging is Amazon (see Case Study 2.16). Its 'frustration free packaging' is marketed as easier to open but has a range of other benefits including recyclability.

If more than one material is used (for example, plastics and paperboard), consumers should be advised to separate the two materials before recycling (see Sect. 3.5.2). The use of adhesives to attach different materials, such as foam cushions to corrugated board, should also be avoided. Specific strategies for individual materials are provided in Table 2.15.

Case Study 2.16 Amazon's 'Certified Frustration Free Packaging'

Amazon is working with its vendors to supply products in 'frustration free packaging', which means it is:

- easy to open
- recyclable
- ships in its own package without an additional shipping box.

Certified packaging can be opened without the use of a knife or box cutter. It is recyclable because it does not include any additional components such as plastic clamshell casings, plastic bindings and wire ties.

Amazon has also developed software to determine the 'right sized' box for each product based on dimension and weight. This helps to avoid over-packaging.

Source: Amazon [64]

Table 2.15 Design strategies to improve recycling

Material	Recycling strategies
Plastic packaging	Specify a plastic that is recyclable in the intended markets for the product (i.e. a recovery system is available to most consumers)
	Try to use only one material, or material combinations that are compatible in the recycling process (see Table 6.7)
	Avoid multi-layer containers
	Try to ensure that polymers used for auxiliary components such as labels, closures, liners and cap seals match that of the container
	If auxiliary components are manufactured from a different material to the container, ensure that the different materials can be easily separated during the washing process
	Consult with recyclers to establish if any components will be problematic in the recovery process or end-product
	Un-pigmented polymers are more valuable as recyclate than pigmented. If colour is required, try to limit it to labels
	Avoid fillers that change the density of the plastic or minimise their use, as they lower the quality of the recycled material
	PVC and PET are incompatible in the recycling process. Avoid PVC labels, closures or tamper-proof seals on consumer packs made from PET
	Avoid wet-strength paper labels on plastic packaging, as they do not disintegrate into pulp during the wash phase and will contaminate the polymer
	Avoid metallic labels and aluminium closures and seals, as they can severely impact the viability of polymer recycling
	Avoid pressure-sensitive adhesives that cover the entire back of the label, as they are difficult to remove and contaminate the recycled polymer
	Incorporate recycled content where possible (subject to food contact requirements)
	Label rigid packaging with the relevant identification code and recycling symbol (see Sect. 3.5.2)
Paper and boxboard	Avoid the use of wax or aluminium coatings, which reduce the yield of recycled fibre
	Avoid plastic/aluminium laminates
	Check with recyclers to ensure that polymer coatings and varnishes, if required, are compatible with the recycling process
	Minimise or avoid the use of non-paper components (e.g., foam pads, plastic film windows, metal tear strips, plastic handles, etc.)
	Minimise the use of inks
	Do not use inks, dyes and coatings that contain heavy metals
	Minimise the use of adhesives; e.g. by using mechanical fastenings such as interlocking tabs
	Check with local recyclers to find out whether they would prefer a water-soluble adhesive or one that can be easily separated out in the pulping process (e.g. some hot melts)
	Avoid highly wet-strength paper (e.g. labels) or cartonboard. These generally don't break down, causing blockages in the pulping process

(continued)

Table 2.15 (continued)

Material	Recycling strategies
	If extra labels are required, they should be made of a paper-based material
	Incorporate recycled content where possible (subject to food contact requirements)
	Label recyclable packaging with the relevant recycling symbol (see Sect. 3.5.2)
Glass	Avoid dark green, dark blue or black glass. These may contaminate recyclable glass (which is sorted into clear (flint), amber and green glass with strict specifications)
	Avoid components that are problematic in the glass recycling process, such as cobalt blue pigment, metal tamper-evident rings and metal-based inks for on-glass printing [5]
	Label with the relevant recycling symbol (see Sect. 3.5.2)
Steel and aluminium	Avoid inks and coatings that might be a contaminant or result in problematic emissions at the refinery (e.g. lead based inks and chlorinated plastics) [5]
	Avoid features made from other metals; e.g. aluminium foil on steel cans [5]
	Use appropriate labelling to encourage consumers to recycle them after use (see Sect. 3.5.2)

Assess the Role of Biodegradable Polymers

Biodegradable polymers are increasingly used because of their potential benefits at end-of-life; for example, as a raw material for composting processes. Many are also made from renewable materials and could, if widely used, reduce reliance on oil for manufacturing plastics.

⇒ Read more about the advantages and disadvantages of biodegradable polymers in Chap. 6.

Biodegradable polymers may be a good option for:

- short life products that are insensitive to moisture and oxygen, that do not require heating in-pack, and are non-carbonated [1]
- packaging that is currently *not* recyclable through existing material recycling systems, such as film and bags
- packaging that tends to contaminate food recovery systems (see Case Study 2.17).

When using biodegradable polymers the design process needs to ensure that the materials will *actually* be recovered by assessing that:

- the material has been certified to a recognised international standard for biodegradability or composting
- the infrastructure exists to collect and reprocess the material.

Case Study 2.17 Food Waste

The waste from fast food outlets comprises fresh produce scraps and packaging from back-of-house, and food and packaging from the restaurant. If the food service packaging is made entirely from paper, cartonboard or compostable polymers (plates, cups, straws, napkins, etc.) then the waste does not need to be separated. It can all be sent to a composting or anaerobic digestion facility.

The waste from supermarkets also includes fresh produce past its prime and any associated packaging, such as plastic bags, film, trays and clamshells. The use of biodegradable polymers for this type of packaging facilitates the recovery of food waste by reducing contamination from plastic packaging (a strategy being pursued by retailers such as Sainsbury's).

Bags made from biodegradable polymers can be used for the collection of compostable food waste and yard waste (weeds and fallen leaves) from households. Once again, this means that the packaging does not need to be separated before the organic material is disposed of in a home composting bin or delivered to a commercial composting facility.

Where biodegradable polymers are used, the packaging should be designed so that it does not compromise the degradation process. For example, coatings and pigments may interfere with degradability and compost certification. Toxic heavy metals in pigments and printing inks (for instance, lead, cadmium, mercury or chromium) could also have eco-toxicity impacts. Potential risks should be assessed to minimise any ecological or health effects during manufacture, use and disposal [65].

Packaging designed for organic recovery, whether through a commercial or home composting system, needs to be labelled appropriately. Consumers should be advised that the material is biodegradable and be given information on how they can dispose of it correctly (see Sect. 3.5.3).

Key steps in the decision-making process for biodegradable packaging are shown in Fig. 2.5. When selecting paper and biodegradable polymers, the designer needs to confirm that they are based on sustainably harvested feedstocks. LCA should also be used to understand and validate the environmental benefits. All materials, whether sourced from renewable or non-renewable materials, have impacts upon the environment, and performing an LCA ensures that all necessary life cycle stages are assessed; that is, that materials are compared on a level playing field.

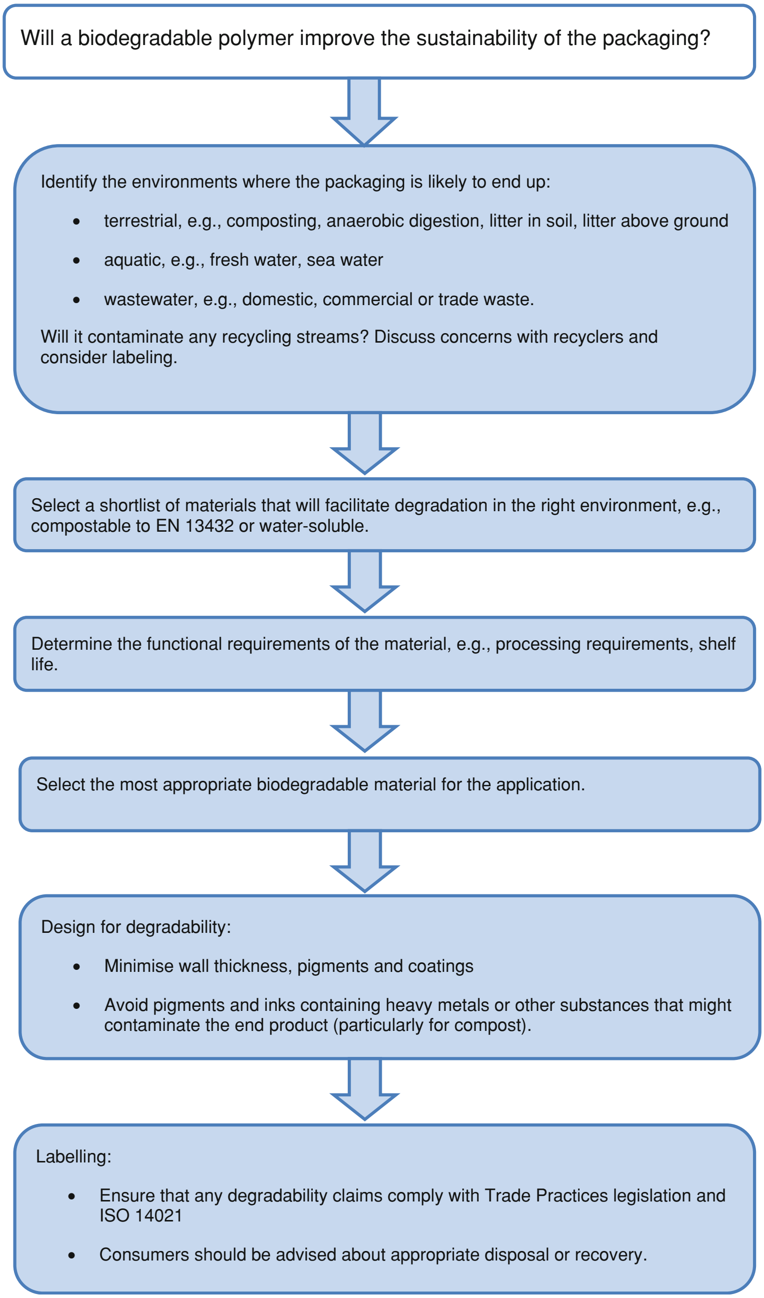


Fig. 2.5 The decision-making process for degradable packaging. *Source*: Based on PACIA [67, p. 12]

Coca-Cola, for example, has developed a bottle made from 30% plant derivatives (sugar cane), which it claims can be recycled through conventional recycling systems without contaminating the recycled polymer [66].

Support Renewable Energy Growth

Renewable energy is generated from sources such as water (hydro power), wind, biomass (e.g. incineration or anaerobic digestion) and solar. Renewable energy is beneficial because it reduces depletion of non-renewable resources and greenhouse gas emissions.

Strategies to promote the use of renewable energy include:

- generating power on-site; for example, through the installation of solar panels on roofs
- using renewable transport fuels; for example, biofuels, where these do not conflict with food security and are found to have the lowest impact
- purchasing 'renewable energy credits' to match the electricity used by the company
- purchasing 'carbon credits', which offset the greenhouse gas emissions of a product or business. The money paid to organisations for carbon credits is used to fund projects such as infrastructure for renewable energy or tree planting to absorb greenhouse gas emissions.

Frito-Lay has purchased renewable energy credits to offset the electricity consumed at all of their US-based manufacturing facilities and has installed solar panels at its manufacturing facility in Modesta, California [68]. These initiatives have allowed the company to use the 'Green-e' label on their SunChips brand of potato chips.

2.4.4 Designing for Safety

Safe ✚

Non-polluting & non-toxic

- Avoiding hazardous substances
- Cleaner production
- Ecological stewardship
- Litter reduction

By focusing on the safe principle the design team will:

- understand the complete life cycle of their packaging component
- identify and avoid the use of hazardous substances in their products
- identify and avoid the production of hazardous substances (including greenhouse gases) throughout the life cycle of the packaging components they use
- identify strategies to reduce litter and the impacts of litter in relevant ecosystems.

Identify and Avoid Hazardous Substances

Conventional risk management principles involving risk identification and hazard risk analysis should be applied to the selection of materials, inks, pigments, coatings, plasticisers and other substances used to produce or use the packaging. A risk management approach involves the following steps [69]:

1. Define the review mechanism.
2. Identify opportunities, risks and barriers.
3. Assess the factors that are within the control of the organisation.
4. Ensure that those within the control of the organisation are acted on.
5. Report on the process.

The design team needs to fully understand the production and manufacturing processes for their packaging and products. A risk assessment should identify any substances used or emitted at any stage of the life cycle of packaging components and their use, including recovery, reuse and reprocessing, that might be toxic to workers, consumers or ecosystems. Information should then be sourced to appropriately assess the safety risk and ensure that packaging is designed to avoid the substances or, as a minimum, that known public safety standards are met. Information, including acceptable limits where applicable, should be included in life cycle maps and packaging specifications.

> ⇒ The European Printing Industry Association has developed an 'exclusion list' for printing inks and related substances based on health and safety concerns. The list includes substances classified as carcinogenic, mutagenic or toxic in relevant European directives and pigment colourants based on antimony, arsenic, cadmium, chromium (VI), lead, mercury and selenium [70].

Bisphenol A (BPA) and phthalates (see below) are two examples of substances that were considered safe but are now the subject of further research and development to overcome potential risks associated with their widespread use.

A document published by Ciba Speciality Chemicals (now BASF) provides information on the compliance of specific pigments and dyes with the European Packaging Directive, US and other international regulations [71].

Bisphenol A

BPA is a chemical used to make polycarbonate and epoxy resins. Polycarbonate is used in the manufacture of reusable baby bottles and reusable outdoor drink bottles, while epoxy resins line most metal food and beverage cans. BPA prevents packaging materials imparting any taste to the product, and it is highly stain-resistant [72].

> ⇒ Proposals to restrict the use of BPA are discussed in Sect. 4.2.3.

⇒ For a review of the literature on health and environmental risks linked to BPA, see reports by Environment California [74] and Green Century Capital Management [72].

BPA leaches out of both plastics and has been found at very low concentrations in food and beverages packaged in these materials. For example, a test of canned foods by Consumer Reports in the United States found BPA in almost all of the 19 products tested [73]. It is absorbed by the human body: a study cited by Environment California [74] found that BPA is present in the urine of 95% of Americans. Many peer-reviewed studies have linked these low dosages to a wide range of developmental and health problems, including prostate effects, breast cancer, heart disease, obesity, attention deficit, altered immune system and early puberty. Pregnant women, infants and children have been found to be most at risk. Environment Canada also noted that BPA enters the environment through waste water, washing residues and leachate from landfills, and has potential to build up in waterways and harm fish and other organisms [75].

As a result, some national, state and local governments have moved to regulate the use of BPA in packaging for infants and young children, particularly in baby bottles and infant formula packaging. Walmart, Toys 'R' Us and Wholefoods have voluntarily stopped selling baby bottles made with BPA, and some food and packaging manufacturers are investigating alternatives to BPA in their packaging [72] (see the Heinz Case Study 2.18).

Case Study 2.18 BPA: Heinz Baby Food

Heinz is considered an industry leader in phasing out the use of BPA because the company has eliminated it from the epoxy resin lining in its baby food cans and has started to remove BPA from baby food jar lids in the United Kingdom [72]. This move is largely in response to consumer concerns about its potential health impact rather than any explicit acknowledgement of a health risk:

> 'Heinz … is pleased to be recognized for our leadership in moving to alternative materials that are Bisphenol A (BPA) free. Heinz has been a leader in food safety ever since our founder started this company in 1869. Although scientific bodies worldwide have concluded that minute levels of BPA are safe, Heinz is proactively exploring alternatives to BPA in response to consumer opinion' [78].

Sources: Green Century Capital Management and As You Sow [72], Heinz [78]

Alternative polymers to polycarbonate include polyamide for baby bottles, and tritan copolyester for reusable drink bottles. There are also alternatives to epoxy coatings on metal cans, including polyester coatings and natural oils and resins, but these tend to cost more and are less effective for highly acidic foods such as tomatoes [72]. Japanese businesses voluntarily reduced their use of BPA between 1998 and 2003 after BPA was detected in canned drinks. According to the Environmental Working Group in the United States [76], companies switched to either a PET lining or an epoxy resin with much lower BPA migration. Another option is polypropylene-lined cans [77].

One of the challenges for manufacturers and regulators is the need to ensure that alternatives to BPA are also thoroughly tested and found to be safe.

Many food and beverage containers, such as the water bottle shown in Photo 2.1, are now BPA-free.

Photo: Helen Lewis

Photo 2.1 BPA-free water bottle

Phthalates

Phthalates are a group of chemicals widely used in personal care products (shampoos, lotions, liquid soaps and so on) and some packaging. They look like clear vegetable oil and are used as 'plasticisers'; for example, to make PVC more flexible. Phthalates can comprise 10–50% of flexible PVC by weight [79].

Like BPA, phthalates can be absorbed in the body through migration into food (in the case of packaging) or through other forms of contact. They appear to act as endocrine disrupters in the human body, and research studies have linked phthalate exposure to health problems including reduced male fertility and rising rates of testicular and prostate cancer. While it is certain that everyone is exposed to low levels of endocrine-disrupting chemicals (including phthalates), there is still a considerable amount of scientific uncertainty about their health impacts [79, p. 14]. A particular concern to health advocates and regulators is the exposure of small children to phthalates in toys because they are more likely to put toys in their mouth. Children are more at risk from ingested or inhaled pollutants because they have less well-developed detoxification mechanisms.

Phthalates are also a common environmental pollutant, as they have been used in a wide range of products since the 1940s. However, the toxicity risks are limited because they readily biodegrade in aerobic environments and their concentrations are generally below levels likely to have toxicity or reproductive impacts on living organisms [80].

While restrictions on the use of phthalates have targeted children's products rather than PVC in general (see Sect. 4.2.3), the risks of using PVC for food and beverage packaging need to be carefully assessed. Based on a comprehensive review of the available data, one academic noted that while 'there is a lack of scientific evidence showing that phthalates have an adverse effect on humans at levels likely to be encountered either environmentally or during normal use of phthalate containing products…the possibility that such a link will be established in future should not be discounted' [79, p. 17].

A common application of PVC in food packaging is the ring of rubbery material, or gasket, which forms the seal inside the metal lid of a screw-topped jar. Products packed in glass jars were tested by the Australian Consumers Association for the presence of phthalates. Of the 25 products tested, 12 contained phthalates at levels above the maximum limits permitted in the European Union [81].

There are many different phthalates used in PVC (see Table 2.16), but the most common is DEHP. (See Table 2.16 for the full scientific name of the phthalate and others mentioned in this paragraph.) This is also the most dominant plasticiser found in the environment. In Europe, DEHP is mainly being replaced by DIDP and DINP, which have been given a lower risk rating by the European Union [80, p. 26]. DEHP, DBP and BBP are classified in the European Union as reproductive toxicants [82]. There are three types of non-phthalate plasticiser suggested as replacements for problematic phthalates: adipates, citrates and cyclohexyl-based plasticisers, although these tend to be more costly and are yet to undergo risk assessments in the European Union [80, p. 26]. A recent innovation is the development by Danish company Danisco of a biodegradable plasticiser to replace phthalates in PVC. The plasticiser is manufactured from castor oil and acetic acid and has been approved for food contact in Europe [83].

Table 2.16 Common phthalate plasticisers used in PVC

Chemical name	Abbreviation
Dimethyl phthalate	DMP
Diethyl phthalate	DEP
Dibutyl phthalate	DBP
Disobutyl phthalate	DIBP
Di-n-hexyl phthalate	DHP
Benzyl butyl phthalate	BBP
Diethylhexyl phthalate	DEHP
Dioctyl tere-phthalate	DOTP or DEHT
Diisooctyl phthalate	DIOP
Diisononyl phthalate	DINP
Diisodecyl phthalate	DIDP

Source: [80, p. 21]

Table 2.17 Examples of heavy metals in packaging

Packaging component	Heavy metal	Source
Glass packaging	Lead	Recycled glass (e.g. lead crystal, automobile glass, mirrors, TV screens)
Plastic crates and pallets	Lead, cadmium and chromium[a]	Black, brown, green, dark blue, orange, red and yellow pigments. Some heavy metals (no longer used in virgin polymers) made from recycled material
Coloured plastic nets	Lead and chromium[a]	Red, yellow and orange pigments
Plastic caps	Cadmium	Yellow, orange, red and green pigments
Plastic shopping bags	Lead and chromium[a]	Gold, yellow, orange, red and green pigments
Plastic non-food bottles	Lead, cadmium and chromium[a]	Yellow, orange and green pigments
Plastic foils coated with aluminium	Lead and chromium[a]	Red, gold and silver coatings

[a] Not all of the chromium was chromium VI. This tends to be associated with red and orange pigments

Source: Based on PIRA International and ECOLAS [42]

Identify and Avoid Heavy Metals

The European Packaging and Packaging Waste Directive specifies that the combined weight of heavy metals (lead, cadmium, mercury and hexavalent chromium) in packaging or packaging components should not exceed a concentration of 100 ppm. 'Toxics in packaging' laws in the United States have the same limit but are stricter than the European Directive because they also prohibit the 'intentional' introduction of any amount of the four restricted metals. Some recycled materials contain heavy metals, but this is acceptable under the European Directive and similar state laws in the United States.

Testing in Europe and the United States has found continuing use of heavy metal based pigments, inks and stabilisers for packaging (see examples in Table 2.17). US tests have also found high levels of heavy metals in shopping bags, particularly lead, mercury and chromium [84], arising from the use of solvent-based inks. A high percentage of flexible PVC bags have also failed tests, including 'zipper bags' used to package bedding and other home furnishings and pouches for pet toys and chews. Almost all of these were imported from Asia.

Support or Use Cleaner Production Initiatives

A full understanding of manufacturing and printing processes may highlight opportunities to reduce the environmental impacts of packaging with cleaner production technologies. Two common pollutants that can be minimised by changing specifications at the design or procurement stage are discussed below: volatile organic compounds (VOCs) and organochlorine compounds.

Emissions of Volatile Organic Compounds

VOCs are natural or synthetic organic substances that have a tendency to vaporise during handling or use, and emissions can be harmful or toxic if inhaled. They can also combine with sunlight and nitrous oxides to generate low-level ozone [85]. Sources of VOC emissions in the packaging industry include solvent-based inks and adhesives (including laminates), as well as cleaners used in printing processes.

Alternatives to solvent-based inks include water-based, ultra-violet curable and litho inks, although these tend to require more energy and may not be suitable for all applications [85, pp. 68–69].

According to Envirowise [85], water-based adhesives or hot melts can be used in some applications instead of solvent-based adhesives to reduce VOC emissions. Hot melt adhesives can cause problems in the paper recycling process, however, because they break up. Because of their similar density to water and fibre, they are difficult to remove. Care should be taken to specify adhesives with a higher or lower density, which are therefore easier to remove from the pulp (such as newer ethylene–vinyl acetate (EVA) hot melts and fast drying polyurethane rubber adhesives). Water-based adhesives do not generate any VOCs but may require more energy for drying and are not suitable for all applications [85].

Henkel has developed a solvent-free lamination adhesive (polyurethane) for food packaging, which according to the company reduces emissions, energy costs and cure times [86].

Chlorine Bleaching Processes for Paper

Elemental chlorine has traditionally been used as the bleaching agent in pulp mills to produce white paper. The wastewater from these mills contains organochlorine compounds such as dioxins that are toxic in the natural environment. Chlorine dioxide is less polluting than chlorine gas and is increasingly used by paper mills. Chlorine combines with lignin (the 'glue' that holds the wood fibre together) to create organochlorine compounds that end up in wastewater, whereas chlorine dioxide breaks apart the lignin and creates organic compounds that are water-soluble and similar to those occurring in the natural environment [87]. Processes that have replaced all of the elemental chlorine with chlorine dioxide are referred to as elemental chlorine-free (ECF). While a significant improvement, ECF processes still generate chlorinated compounds, which make the wastewater too corrosive to recycle. The result is that effluent is treated and discharged to receiving waters [60].

There are alternatives to traditional chlorine bleaching:

- replacing chlorine compounds with oxygen-based compounds in the first stage of the bleaching process, which allows the waste water from this stage to be reused
- replacing all chlorine compounds in the bleaching process with oxygen-based chemicals such as ozone or hydrogen peroxide, potentially allowing all the wastewater to be reused. (In reality most mills moving to a totally chlorine free process still discharge wastewater to the receiving environment [60].)

Processes that have eliminated all chlorinated bleaching agents are referred to as totally chlorine-free (TCF). The Chlorine Free Products Association in the United States has introduced an eco-labelling scheme for TCF and processed chlorine-free (PCF) products [88]. The PCF logo can be used for recycled papers that meet minimum recycled content standards and are bleached without any chlorine compounds (see Sect. 3.5.6).

⇒ Chapter 3 provides information on the use of logos and labels.

To reduce the environmental impact of bleaching processes for paper and paperboard packaging, it's necessary to:

- use unbleached fibre where feasible, or
- if white paper or paperboard is required, specify TCF or PCF fibre.

⇒ Chapter 6 describes the environmental impacts associated with paper recycling.

Greenhouse Gas Emissions

Greenhouse gas emissions are generated at every stage of the packaging life cycle: during material extraction or harvesting, manufacturing, filling, transport, use and disposal. Most of these emissions, particularly carbon dioxide, are associated with energy consumption, but methane is also generated when organic materials break down in landfill.

Many of the strategies to reduce energy consumption and associated greenhouse gas emissions have already been discussed, including reducing the size or weight of packaging and using recycled rather than virgin materials. Emissions can also be reduced in other aspects of the business; for example by:

- undertaking an energy audit, which will identify opportunities to reduce energy consumption in manufacturing, administration and distribution processes
- purchasing renewable energy or 'carbon offsets'.

Some businesses are using 'carbon labels' to inform consumers about the greenhouse gas emissions associated with the production of food and packaging (see Sect. 3.5.8). The aim of these labels is twofold: to drive efficiencies in the supply chain and to encourage consumers to purchase lower carbon products.

Ecological Stewardship

It is important to know the source of raw materials, particularly for timber products (pallets and crates) and the fibre used to manufacture paper bags, paperboard packaging and corrugated boxes. Timber and paper products from sustainably managed forests should be specified, with preference for those certified by a third party organisation such as the Forest Stewardship Council (FSC) (see Sect. 3.5.7). A number of other national schemes have been assessed and approved by the Program for the Endorsement of Forest Certification, a non-government organisation which has its own labelling scheme for certified products. Demand from pulp and paper manufacturers for woodchips certified by the FSC is starting to drive change in forestry operations. For example, Australian suppliers of wood and woodchips faced a downturn in demand in 2009, particularly from Japanese customers who didn't want to buy woodchips from native forests [89]. As a result, the Tasmanian state government has asked Forestry Tasmania and the largest woodchip exporter, Gunns, to seek FSC certification.

There are no certification schemes for sustainable sourcing of other packaging materials, but similar issues need to be considered during the design and procurement process:

- How and where was the material extracted/harvested?
- How are these impacts managed?
- Do suppliers comply with all relevant legislation?

Similarly, it is important to understand the raw materials and processes used to manufacture biopolymers. Is the raw material grown using sustainable agriculture principles? Are biopolymers competing for food supplies and helping to drive up prices?

Litter Reduction

Design for litter reduction is important for products likely to be consumed away from home, such as single-serve beverages, sweets, snacks and salads. Structural design can assist by minimising the number of parts that break away from the main pack and are likely to end up as litter. For example, the 'ring-pull tabs' on aluminium drink cans used to completely detach from the can after opening. These were sharp and caused cuts when people accidently stood on the tabs. The tab was redesigned so that after lifting it is levered beneath the opening and stays attached to the can [90].

For packaging such as takeaway food packs and straws that often end up in the litter stream, the use of a biodegradable material such as paper or cartonboard is preferable. Biodegradable polymers certified to a relevant standard may reduce the impacts of litter, but there is insufficient public information available on how fast and to what the extent they break down in open environments, such as soil or the ocean, instead of a controlled composting environment. Messages on the label can also be used to encourage consumers to dispose of the packaging appropriately, in a litter or recycling bin (see Sect. 3.5.5). Table 2.18 includes strategies to prevent the incidence or impact of litter.

Table 2.18 Strategies to prevent the incidence or impact of litter

Minimise the number of separable components that can be littered (e.g. straws, tamper evident seals, trays, spoons and forks)
Provide information to the consumer to encourage responsible disposal
Work with recyclers and local/state governments either directly or through industry associations and non-government organisations to implement public place recycling bins
Where appropriate consider the use of a biodegradable material certified to a relevant standard

2.5 Selecting Materials

> 'There is no such thing as a fundamentally good or bad packaging material: all materials have properties that may present advantages or disadvantages depending on the context within which they are used' [91, p. 8].

The choice of packaging materials has a significant impact on sustainability, but it is not possible to say that a particular material should always be avoided or favoured. The impacts and benefits of a material are highly dependent on how and where it is sourced, manufactured, used and recovered.

Tables 2.19 and 2.20 show how the sustainable packaging framework can be used to evaluate the advantages and disadvantages of materials for a particular application. These are generic examples only—the specific benefits will depend on the product, its packaging requirements, the supply chain, the availability of recycling facilities and so on.

A more detailed description of the life cycle impacts of common packaging materials is provided in Chap. 6.

Table 2.19 Evaluating packaging materials against the four principles of packaging sustainability

Sustainable packaging design principles		Material			
		Aluminium	Steel	Glass	Paper and board
Effective	+ve	Broad range of barrier properties (inert) Less dense than steel or glass Can be pressed and drawn into many different shapes Opaque (good for food preservation)	Impervious to gases, aromas, light and micro-organisms Opaque (good for food preservation) Can be pressed and drawn into many different shapes High impact resistance No refrigeration required	Impervious to liquids, gases, aromas, and microorganisms Clarity allows the consumer to see the contents Can be hot-filled Odourless	Versatile (e.g. rigid or flexible, can be formulated to give a range of properties) Can have a good printing surface Impermeable to liquid and gas if laminated Transfers heat well Relatively inexpensive
	−ve	Consumer cannot see the contents	Corrodes in contact with water unless coated Consumer cannot see the contents	Low impact resistance, leading to high wall thickness requirements Higher density than plastic or board, which may lead to high environmental impacts from transport	Non-laminated and non-waxed grades are not waterproof, leading to property degradation Not a barrier against microorganisms or animals Low impact resistance Consumer cannot see the contents
Efficient	+ve	Lightweight	No refrigeration required	Can be made with high recycled content	Low density
	−ve	Energy-intensive (virgin material)	Energy-intensive (virgin material)	Energy-intensive (virgin material)	Energy- and water-intensive (virgin material)
	Specific design strategies	Downgauge as much as possible Maximise recycled content	Downgauge as much as possible Maximise recycled content	Downgauge as much as possible Maximise cullet content	Downgauge as much as possible Maximise recycled content

(continued)

Table 2.19 (continued)

Sustainable packaging design principles		Material			
		Aluminium	Steel	Glass	Paper and board
Cyclic	+ve	Can be recycled an infinite number of times with minimal loss of technical properties	Can be recycled an infinite number of times with minimal loss of technical properties	Can be recycled an infinite number of times with minimal loss of technical properties	Renewable raw material Can be recycled many times but fibre length and strength reduces following subsequent reprocessing
	-ve	Non-renewable resources Many foils are not recyclable due to food contamination, e.g. confectionary wrappers	Non-renewable resources	Non-renewable resources (but abundant) Recovery is limited by mixing of colours in the recycling stream and inability to utilise all fine glass particles	Each cycle reduces cellulose fibre length, reduces properties. This limits the number of cycling loops possible Wax-coated paper and board are not recyclable and liquid paperboard is difficult to recycle
	Specific design strategies	Maximise recycled content Add recycling logo to label Minimise contamination for recycling stream	Maximise recycled content Add recycling logo to label	Maximise recycled content Some colours may be less recyclable in some regions Add recycling logo to label	Recycled content If possible, avoid wax coatings Avoid combining with other materials, e.g. plastics Add recycling logo

(continued)

Table 2.19 (continued)

Sustainable packaging design principles		Material			
		Aluminium	Steel	Glass	Paper and board
Safe	+ve	Minimal direct wildlife impacts in litter	Minimal direct wildlife impacts in litter	Inert—no migration into food products Minimal direct wildlife impacts in litter	Biodegrades in the natural environment – no direct hazard to wildlife
	−ve	Does not degrade	Does not readily degrade	Durable in litter and broken glass is a hazard	Relatively high greenhouse gas emissions from manufacturing/recycling Greenhouse gas emissions from landfill Fibre may be harvested from old growth or unsustainably managed forests Bleaching generates waterborne pollutants, e.g. dioxins
	Specific design strategies	Advise consumers not to litter	Advise consumers not to litter Avoid Bisphenol A (BPA) liners in packaging for children or infants	Advise consumers not to litter	Source from certified forests Avoid bleached packaging Otherwise, use totally chlorine-free (TCF) or process chlorine-free (PCF) bleaching Advise consumers not to litter

Table 2.20 Evaluating thermoplastic polymers against the four principles of packaging sustainability

Sustainable packaging design principles		Thermoplastic polymer material			
		Non-renewable		Renewable	
		Non-degradable[a]	Degradable[b]	Non-degradable[c]	Degradable[d]
Effective	+ve	Wide range of mechanical properties Versatile, can be processed into complex shapes Translucent to opaque, coloured High impact resistance Resistance to most chemicals Lower density than metals and glass			
	−ve	Limited thermal stability Properties may be affected by light		Limited thermal stability Properties may be affected by light Some may not be as water resistant as synthetic polymers. Density may be higher than non-renewable polymers	
Efficient	+ve	Lightweight Can be processed at low temperatures (less energy) Most manufacturing processes generate little waste (scrap can be recycled in-house)			
	−ve	Some processes generate non-recyclable scrap during manufacturing (e.g. laminated film)		Due to higher density and lower strength, may require more material than fossil-based thermoplastics in order to fulfill function Some polymers must be modified to avoid moisture uptake, which adversely affects processing	
	Specific design strategies	Reduce material weight, e.g. downgauge			
Cyclic	+ve	Technically recyclable – depends on packaging format and availability of recycling services	Compostable if certified to a recognised international standard, e.g. for commercial or home composting	Renewable raw materials	Renewable raw materials Compostable through an organic recycling process if certified to a recognised international standard

(continued)

Table 2.20 (continued)

Sustainable packaging design principles		Thermoplastic polymer material			
		Non-renewable		Renewable	
		Non-degradable[a]	Degradable[b]	Non-degradable[c]	Degradable[d]
	−ve	Degradation can occur during recycling (e.g. colour contamination, mixed grades)	Non-renewable Oxodegradable polymers are not compostable and may contaminate recycling of other thermoplastics	Not compostable or currently commercially recyclable. May contaminate recycling of non-renewable thermoplastics	Appropriate composting services may not be widely available. May contaminate recycling of non-renewable thermoplastics
	Specific design strategies	Confirm compatibility with recycling services Design for recycling, e.g. specify a polymer that is widely recycled, use only one material	Design for degradation, e.g. minimal inks Include specific disposal guidance for consumers	Include specific disposal guidance for consumers	Confirm compliance with composting standards Design for composting, e.g. minimal inks Include a composting message for consumers
Safe	+ve	Lower greenhouse emissions than metals or glass	Lower greenhouse emissions than metals or glass	May have a higher specific gravity than non-renewable polymers, minimising hazard to marine wildlife	May degrade May have a higher specific gravity than non-renewable polymers, minimising hazard to marine wildlife
	−ve	Some polymers contain BPA or phthalates Some pigments may contain heavy metals Polymers with a specific gravity of less than 1 can pose a hazard to marine wildlife	Some pigments may contain heavy metals Impacts in litter are not well understood	Some pigments may contain heavy metals May be a hazard to wildlife in litter	Some pigments may contain heavy metals May generate higher greenhouse emissions in manufacturing and in landfill Impacts in litter are not well understood

(continued)

Table 2.20 (continued)

Sustainable packaging design principles	Thermoplastic polymer material			
	Non-renewable		Renewable	
	Non-degradable[a]	Degradable[b]	Non-degradable[c]	Degradable[d]
Specific design strategies	Minimise or avoid heavy metals Validate safety for food applications e.g. leaching of monomers, additives Avoid BPA and phthalates in packaging for children or infants Advise consumers not to litter	Validate safety of degradation additives in the natural environment Avoid pigments with heavy metals Advise consumers not to litter	Avoid pigments with heavy metals Advise consumers not to litter	Avoid pigments with heavy metals Advise consumers not to litter

[a] Includes all conventional commodity polymers, e.g. PET, HDPE, PVC, LDPE, PP

[b] Includes biodegradable polymers made from crude oil or natural gas, e.g. aliphatic aromatic copolyesters as well as oxodegradable polymers made by combining a conventional oil/gas derived polymer with a prodegradant additive

[c] Includes renewable polymers made from modified starch specifically designed not to degrade, including those blended with non-renewable thermoplastics

[d] Includes some biodegradable polymers derived from corn starch, wood or other renewable material

2.6 Conclusion

Design is critical to the achievement of packaging sustainability goals. Most of the decisions that impact on sustainable development, including the choice of materials and processing methods, are made at the design stage. For this reason, life cycle thinking must be embedded in the product-packaging development and review processes to achieve better outcomes.

A framework for embedding sustainable development principles into the packaging design process has been presented in this chapter. However, implementing this framework requires a good understanding of:

- the function of packaging components
- the values and expectations of consumers (see Chap. 3)
- the corporate, brand and product sustainability positioning (see Chap. 3)
- global packaging regulations and emerging policy trends (see Chap. 4)
- the environmental life cycle impacts of products, packaging and materials (Chaps. 5 and 6).

The selection and use of appropriate decision-making tools (Chap. 7) to embed sustainable development in product and packaging design processes should also be considered as part of the packaging for sustainability strategy.

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