CHAPTER

27

From Recycling to Eco-design

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27.1 INTRODUCTION

Regulatory requirements and the rising price of materials due to their scarcity urge product and system designers to integrate recycling and the reduction of environmental impacts throughout the life cycle as early as possible into the design process. In the 1990s, designers began to take into account the effects on the environment of product life cycle phases. Efforts must still be made, in particular in the manufacturing and end-of-life phases. One possible strategy—design for recycling—can be defined as designing a recyclable product and using recycled materials to replace virgin materials. Several factors slow down the design to make products recyclable, including technical barriers and barriers linked to the traceability of materials due to their potential contamination.

27.2 PRINCIPLE OF MATERIAL DESIGN FOR RECYCLING

Design for recycling is an eco-design strategy. Eco-design is a systematic approach allowing the design of more environmentally friendly products. For a company with a strategy to reduce its environmental impacts, the first stage is to review all the processes intervening in the design of a product and to find solutions to reduce the impacts on the product's life cycle. Several strategies can be adopted, as summarized in Figure 27.1. In the materials choice phase, one can choose less impacting materials; reduce the quantities of materials; improve process techniques, transport, and the usage phase; and optimize the life cycle and end-of-life of products.

It is widely accepted that the usage phase is highly impacting for energy-consuming products with long life cycles because these

Handbook of Recycling
http://dx.doi.org/10.1016/B978-0-12-396459-5.00027-1

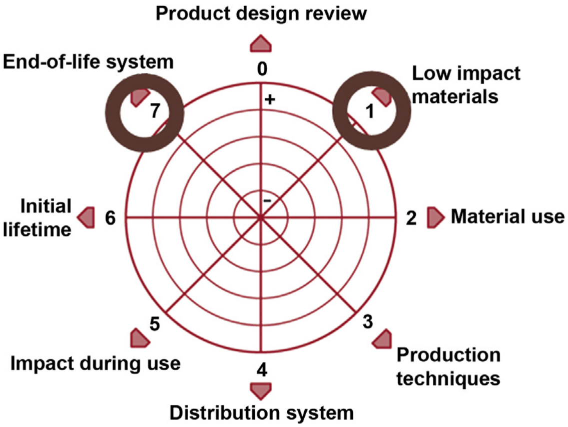

FIGURE 27.1 The wheel of eco-design strategies (Crul and Dieh, 2009).

impacts have a direct effect on climate change. Nevertheless, the impacts of the product manufacturing phase must not be forgotten because the effects on mining resources and nonrenewable energies are irreversible. These resources are limited and impact the extraction phase due to their increasingly low concentrations and therefore higher extraction costs. One solution is to reuse or recycle the product's component materials at their end of life.

27.3 ECO-DESIGN STRATEGIES FOR RECYCLING

A recyclable material must maintain its mechanical and chemical properties and be able to be sorted by recycling companies. Eco-designing recyclable materials means to make them transformable and sortable with an acceptable cost-to-performance ratio. On the wheel of eco-design, strategy 1 is to take into account the limits on resources, while strategy 7 is to take into account the limits of sorting processes. These two limits lead to the consideration of design constraints on the choice of materials and on their association.

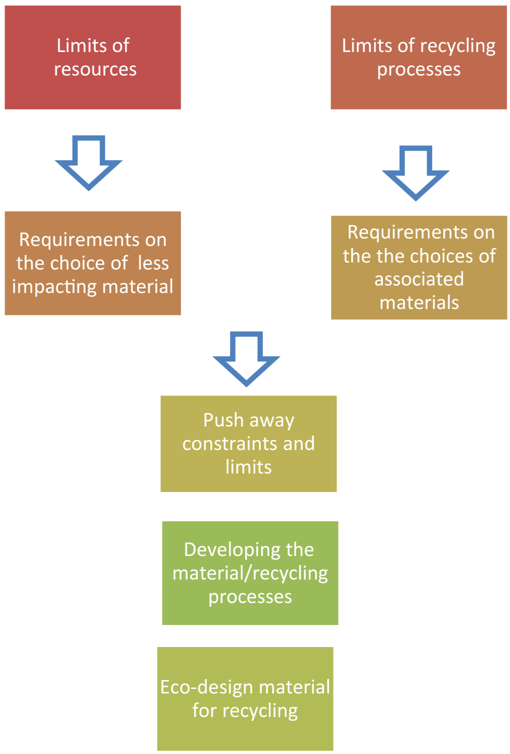

FIGURE 27.2 Principle of the eco-design of materials.

To push these limits further means to develop the materials–sorting process combination, which is the definition of the eco-design approach for materials (Figure 27.2).

27.4 IS RECYCLING REALLY LESS IMPACTFUL ON THE ENVIRONMENT?

For polymers, it is important to remember that 95% of the energy required to produce 1 kg is due to the extraction and refining of the oil (Johnstone, 2005). When virgin polymers are replaced with recycled polymers at rates close to 100%, the recycling scenario is more advantageous than energy recovery. Furthermore, certain polymers can follow several recycling cycles (Assadi, 2002).

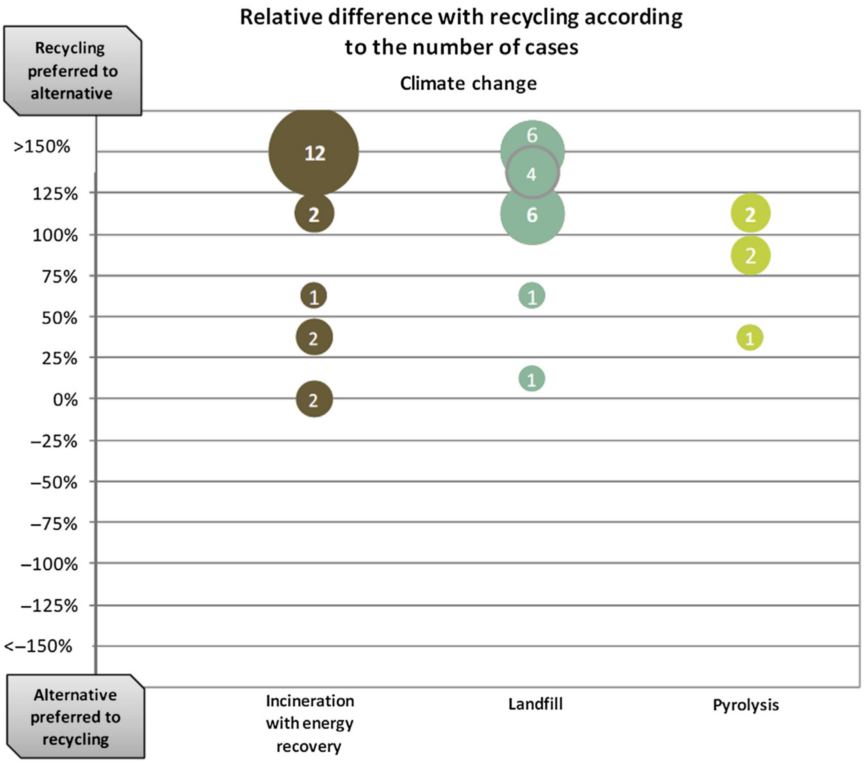

FIGURE 27.3 Relative differences between the various scenarios of polymer treatment at their end of life or recycling with respect to their effect on climate change. The bubble is proportional to the number of studies and the impact value of the same rank (WRAP, 2010).

A study conducted (WRAP, 2010) on the environmental life cycle analysis of the scenarios of different end-of-life polymer treatments shows that the number of studies in favor of the recycling scenario (Figure 27.3) is higher than the number favorable to incineration scenarios with energy recovery or burying in a landfill.

27.5 CURRENT LIMITS FOR ECO-DESIGN FOR RECYCLING STRATEGIES

In view of the medium-term shortages forecasted for certain resources, the efforts to improve material recyclability (Millet, 2003) have led material recyclers to improve sorting processes. They also encouraged designers to reduce the quantity of materials in products and to choose recyclable and associated materials so that they are potentially sortable. There are still several difficulties linked with recycling materials from end-of-life products. These products are collected and treated at their end of life (Figure 27.4), which requires sorting out complex mixtures after grinding (Reuter, 2006), despite eco-design efforts to recycle new products. The second difficulty is linked to the two most representative industrial sorting technologies (Table 27.1) in the recycling sector that do not make it possible to sort out materials using a physico-chemical sorting technique: density separation when the

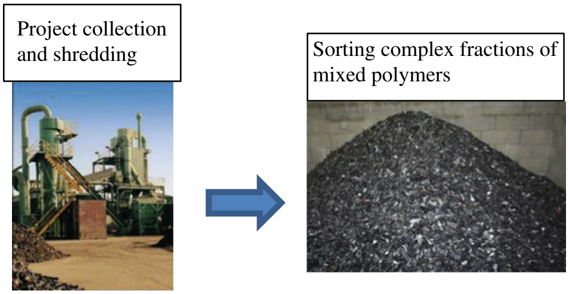

FIGURE 27.4 End-of-life product scheme.

densities overlap or fast spectrometric sorting (near infrared) when polymers are dark-colored. In 2009, 24.3 Mt of polymer waste were generated in Europe, yet only 22.5% on average were recycled in all sectors combined (PlasticsEurope, 2010).

Other choices have been envisaged by designers to reduce environmental impacts, such as the use of biodegradable or biosourced materials. In the first case, the end-of-life impacts can be reduced to avoid the accumulation of waste in landfills.

The second case appears to reduce the use of nonrenewable resources, but in reality there is a transfer via another impact. Eco-profiles

TABLE 27.1 Current Limits of Detection Processes

Physical and chemical sorting	Densimetric sorting (Hwang, 1995; Altland, 1995)	☺ Low cost, industrial scale ☹ Not adapted for overlapped density <0.12 g/cm^3
	Froth flotation sorting (Fraunholcz et al., 2004)	☺ Low cost ☹ Laboratory scale
	Triboelectric sorting (Hearn and Ballard, 2004)	☺ Low cost, industrial scale ☹ Sensitive to moisture and dust, does not sort complex mixed fractions, not able to sort certain polymers
Fast spectrometric sorting	Absorption near infrared (Huth-Fehre et al., 1998)	☺ Very fast sorting, industrial scale ☹ Does not detect dark polymers or polymers closed in formulation
	Absorption medium infrared (Florestan et al., 1994)	☺ Identification of white and dark polymers ☹ Sensitive to surface condition and reflectance signal very weak to identify C—H bonds, not compatible with fast detection
	X-ray fluorescence X (Kang and Schoenung, 2005; Biddle, 1999)	☺ Fast detection, industrial scale, industrial, detection of additives ☹ Does not detect polymers except poly(vinyl chloride)
	X-ray transmission: difference of atomic density analysis (Mesina et al., 2007)	☺ Fast detection, detection of metals at an industrial scale ☹ Possible for polymers but at a laboratory scale
	Laser-induced plasma spectroscopy (LIPS) (Solo-Gabriele et al., 2004; Anzano et al., 2006; Barbier et al., 2013)	☺ Identification of white polymers ☹ Weak signal, not compatible with fast detection
	Ultraviolet fluorescence (Pascoe, 2003)	☺ Many applications for food at the industrial scale ☹ No application for polymers

☺ Positive points for sorting, ☹ Negative points for sorting

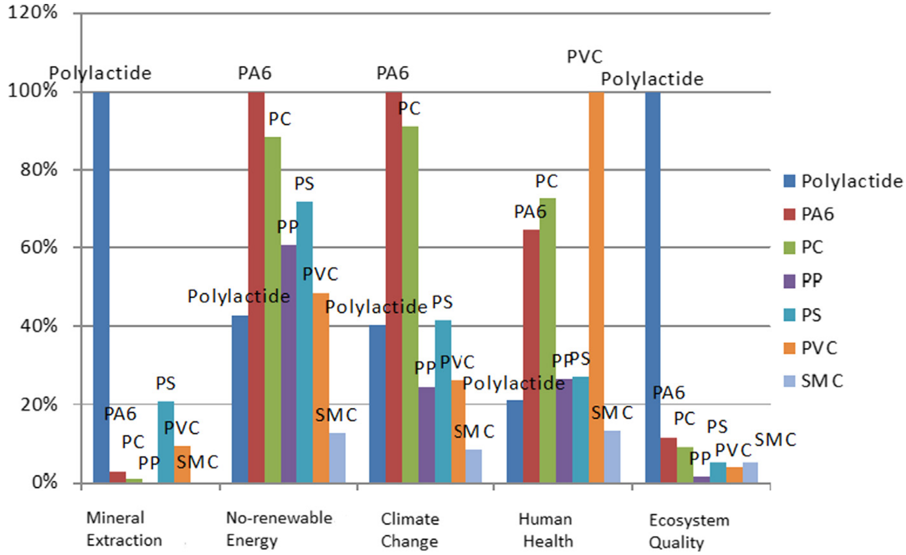

FIGURE 27.5 Comparison of environmental impacts per kilogram of polymers, Impact 2002 method.

(Figure 27.5) of various polymers from the mining extraction phase to the granule production phase were produced using the life cycle analysis modeling tool Simapro, the Impact 2002 method, and Ecoinvent data. The comparison of polylactic acids (PLAs; polymers originating from agricultural resources) with biodegradable and other polymers allowing the same type of application but originating from resins made with oil components shows that there is a transfer of the impacts. PLAs have a significant impact on mining resources due to the use of phosphate minerals as fertilizer for agriculture.

Nonrenewable resources are also significant due to the use of nitrogenous fertilizers originating from oil and the energy used by agricultural machinery.

In conclusion, the improvement of product design has driven the improvement of product recyclability, but limits still exist.

27.6 MARKET DEMAND

The recycling market is in full development (Johnstone, 2005), and the prices of recycled materials exist for metals and polymers. However, the market is still not sustainable and the prices of secondary raw materials are more volatile than those of primary raw materials.

Within the framework of a study carried out with the ADEME (French Environment and Energy Management Agency) and the club of French manufacturers CREER (Maris, 2007), a survey was conducted in 2008 with eight French groups concerning the acceptability of recycled materials, using interviews and questionnaires. The answers provided reliable data for seven companies consisting of manufacturers and original equipment manufacturers in the following sectors: electrical safety, automobiles, office furniture, and small electrical appliances, as well as waste collectors. This survey was completed with interviews with a recycled material producer and a consumers' association. The population targeted per company was classified by activity: the executive management, the buyers, the designers, the marketing department, and the quality and after-sales staff.

The survey results showed that all of the companies used recycled materials, including

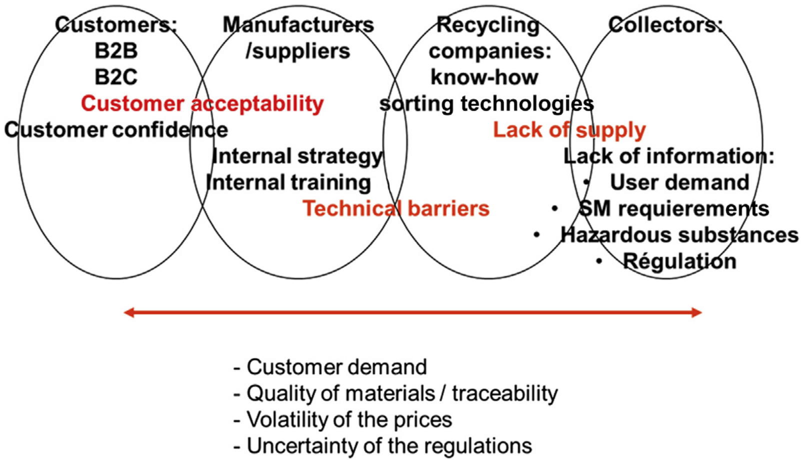

FIGURE 27.6 Barriers to the use of recycled materials.

for certain types of components whose technical performance requirements were fairly high, but they did not all integrate this usage into their strategy. The companies' motivations were both economic (linked to price increases or the scarcity of primary raw materials) and environmental. The main barriers expressed by the respondents (Figure 27.6) from the companies during the survey were:

- The quantity and quality of the recycled materials
- Technical barriers due to constraints on product applications (expressed by recyclers and manufacturers)
- Consumer acceptance

The consumer acceptance of recycled materials is a barrier linked to the traceability of materials due to their potential contamination.

According to the data published by PlasticsEurope (2009), the polymers the most often sold to transformers are polyethylene terephthalate (PET), polyethylene, and polypropylene (PP) for the following sectors: packaging, automotive, household appliances, and electrical products. PET applications are especially for colorless materials. PP is often colored with carbon black according to the application. These polymers represent the most important potential sources of recycled material.

27.7 CONCLUSION

Improving the environmental impact of materials means using recycled materials in new products and making this material recyclable when new products of different design and manufacturers' brands are treated together. To reach this objective, it is necessary to develop the materials–sorting process. Furthermore, while the demand for recycled materials already exists, it is necessary to find solutions to the problems linked to the risks due to lack of supply and the traceability of the recycled materials. Material traceability is a prerequisite to widespread acceptance by users and consumers.

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