

Cradle to Cradle Design Guidelines

I. Problem Statement

Internet-based companies ship millions of books, CDs, DVDs and videos each year. A large percentage of the shipping packaging associated with these purchases, primarily corrugated paperboard and plastic, ends up in landfills. Not only does this represent a significant loss of material, but in the U.S. landfills are also one of the largest manmade sources of methane, a potent greenhouse gas. Internationally, packaging waste is a major concern due to limited landfill space and its environmental impact. In response to these concerns, more than twenty-eight countries, including the E.U., Japan and Canada have enacted packaging legislation to encourage the design and development of more environmentally preferable packaging.

Corrugate, plastic, and various types of void fill are the materials most commonly used for e-commerce shipping packaging and for the larger parcel shipping industry. Together, corrugate and plastic represent roughly 25% of all packaging discarded in 2000. (MSW in U.S. 2000: Facts and Figures). By weight, corrugated paperboard is the most significant component of the 45 million tons of discarded containers and packaging that ended up in landfills in 2000 (MSW in U.S. 2000: Facts and Figures). While corrugated paperboard enjoys a high recovery rate for recycling, its recovery rate in the residential sector (where most e-commerce shipping packaging ends its useful 'life') is significantly lower than in the commercial/industrial sector. The lack of infrastructure for systematic corrugated paperboard and packaging recovery in combination with the distributed nature of residential delivery of e-commerce packages and existing consumer behavior suggests that these materials will become an increasing burden within municipal waste streams.

Despite recent declines in the U.S. economy, e-commerce sales to consumers are rapidly growing and projected to be \$51.48 billion, for a growth rate near 40% for 2002 (BizRate.Com). It is unclear how much of the more than 18 million packages that are handled each day by UPS and FedEx are due to e-commerce, but the number is definitely growing (Business Week, May 21, 2001). As e-commerce evolves, it seems likely that certain products will dematerialize into an Internet-based flow of electrons with no need for packaging. However, for those products that continue to need packaging, Cradle to Cradle Design provides a comprehensive vision of how the materials and systems used for e-commerce packaging can be redesigned and integrated to produce a more sustainable flow of packaging services.

E-commerce presents an ideal opportunity for system-wide implementation of innovative packaging solutions due to its dependence on highly integrated technology for product distribution and returns. E-commerce is strategically oriented to respond to the needs of the domestic and global marketplace. As international measures move towards extended producer responsibility, fees, and design for environment criteria, competitive participation will increasingly mean working throughout the packaging and logistics supply chain to ensure that the entire life cycle of packaging services addresses these issues.

II. Introduction to Cradle to Cradle Design

Cradle to Cradle Design is a system of thinking based on the belief that human design can approach the effectiveness and elegance of natural systems by learning from nature and incorporating its patterns. Industry can be transformed into a *sustaining* enterprise—one that creates economic, ecological, and social value—through thoughtful and intentional design that mirrors the safe, regenerative productivity of nature and eliminates the concept of waste.¹



Background: The Cradle-to-Grave Legacy

Manufacturing systems of the Industrial Revolution are based on a one-way, cradle-to-grave stream of materials—a model that takes, makes, and wastes. Materials are mined and refined, products are assembled, distributed, used by consumers, and then discarded to landfills or incinerators. Each step in this stream typically creates unintended environmental and health impacts. The advent of modern industrial processes has had the added consequence of making many processes and materials more toxic. Today, the legacy of the cradle-to-grave model is routine headline news, profoundly affecting the air we breathe, the water we drink, the climate we live in, the diseases we suffer from, and global politics.

In response to widespread environmental degradation, governments and industries have adopted a strategy known as “eco-efficiency”—minimizing waste, pollution, and natural resource depletion. Many companies have realized significant cost savings and reduced environmental impacts by embracing eco-efficiency. But long-term prosperity depends not on the efficiency of a fundamentally destructive, cradle-to-grave system. It depends on the effectiveness of processes designed to be sustaining, healthy and renewable in the first place.

A New Paradigm: Cradle to Cradle Design

Cradle to Cradle Design offers an alternative. It rejects the assumption that human industry inevitably destroys the natural world, or that the demand for goods and services is the ultimate cause of environmental ills. Instead, it embraces abundance, human ingenuity, and positive aspirations.

Today, with our growing knowledge of the living earth, our designs can reflect a new spirit. Cradle to Cradle Design incorporates this new ecological awareness at every level of human endeavor. Its principles are built on the intelligence, abundance, and effectiveness of natural systems—the flows of energy and nutrients that support the Earth’s biodiversity.

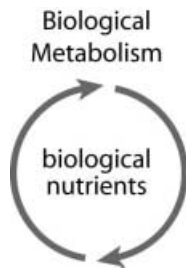
Emulating Nature’s Material and Energy Flows

Nature’s ecosystems function on some key principles that human design can emulate. First, there is no “waste” in nature; the waste from one organism provides nutrients for another. Second, all life on earth is fueled by solar energy. Third, life thrives on diversity, constantly adapting to fill niches. Cradle to Cradle Design models human industry on these natural principles. It envisions a world powered by the sun where growth is good, waste nutritious, and productive diversity enriches human and natural communities.

The application of cradle-to-cradle principles to industry creates cyclical material flows (cradle-to-cradle rather than cradle-to-grave) that, like the earth’s nutrient cycles, eliminate the concept of waste. Each material in a product is designed to be safe and effective, and to provide high quality resources for subsequent generations

¹ Cradle to Cradle Design is based on principles of Industrial Ecology and Design for Environment (DfE). Similar to industrial ecology, materials and energy flows are conceived as ‘metabolisms’ and like DfE, it proposes that we design with the environment in mind, considering all phases of the product life cycle.

of products. All materials are conceived as nutrients, circulating safely and productively in one of two “metabolisms”—the biological metabolism and the technical metabolism.



The Biological Metabolism

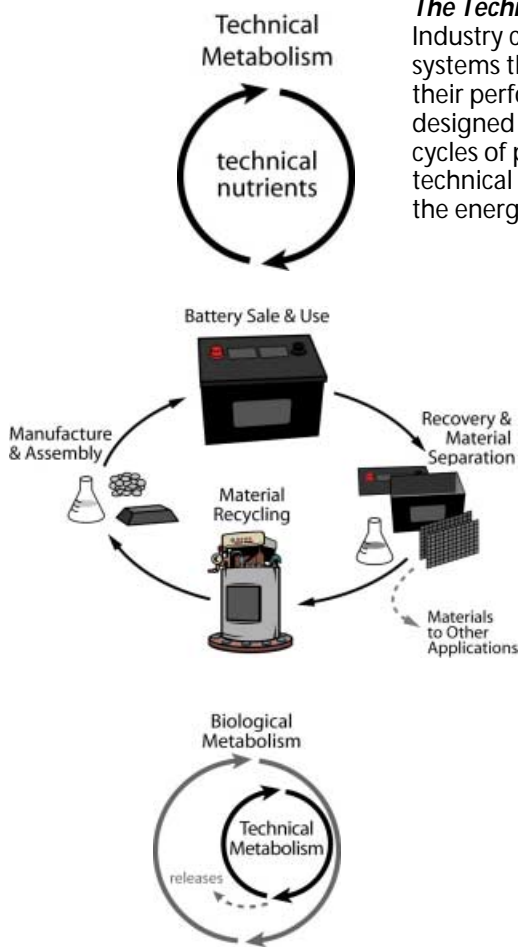
The *biological metabolism* is the system of natural processes that support life. These processes include the degradation of organic materials and their incorporation into organisms—cyclical, and ultimately fueled by sunlight. Materials that contribute to the productivity of the metabolism are *biological nutrients*. Ideally, products of human industry designed from biodegradable, ecologically safe materials participate in the biological metabolism after use through decomposition.

Example: Upholstery Fabric

Upholstery fabrics, which wear out with use, can be designed from biological nutrients that can be returned to ecosystems after use. Climatex® Lifecycle™ fabric is an example of this type of product. The fabric is a blend of pesticide-residue-free wool and organically grown ramie, dyed and processed entirely with non-toxic chemicals. All its product and process inputs were defined and selected for their human and ecological safety within the context of a biological metabolism. Currently, the fabric trimmings (process ‘waste’) are used by garden clubs as mulch for growing fruit and vegetables, returning the textile’s biological nutrients to feed new growth.



The return of Climatex Lifecycle’s nutrients to the biological metabolism depends on its appropriate application and post-use handling. The design must facilitate the clean separation of the fabric from materials that cannot function as biological nutrients, like synthetic foams. Substances used to treat and clean the fabric should also be compatible with the biological metabolism. Finally, the post-use cycling of the fabric’s nutrients will likely rely on a well run composting system.



The Technical Metabolism

Industry can also be modeled after natural processes to create *technical metabolisms*, systems that productively cycle industrial materials. These materials, valuable for their performance qualities and typically 'non-renewable,' are *technical nutrients*, designed to circulate safely and perpetually through cradle-to-cradle product life cycles of production, use, recovery, and re-manufacture. The processes of the technical metabolism are industrial rather than natural, but ideally are also fueled by the energy of the sun in the form of renewable energy.

Example: Batteries

The well-developed system for lead-acid battery recovery provides a provocative model for the development of technical metabolisms. Car batteries are valuable to customers for storing and providing electricity by design, but incidentally pose risk to customers and the environment as a result of the hazardous materials they contain. To reduce the risk of the release of hazardous materials, economic incentives have been built in to encourage the return of old batteries to authorized locations with credit towards a new battery. Old batteries are sent to secondary lead smelters where the material value of the lead, plastic and the acid is recovered for use in new batteries. Over 95% of all lead and plastic from recovered car batteries is recycled, making it the most recycled consumer product in the U.S.

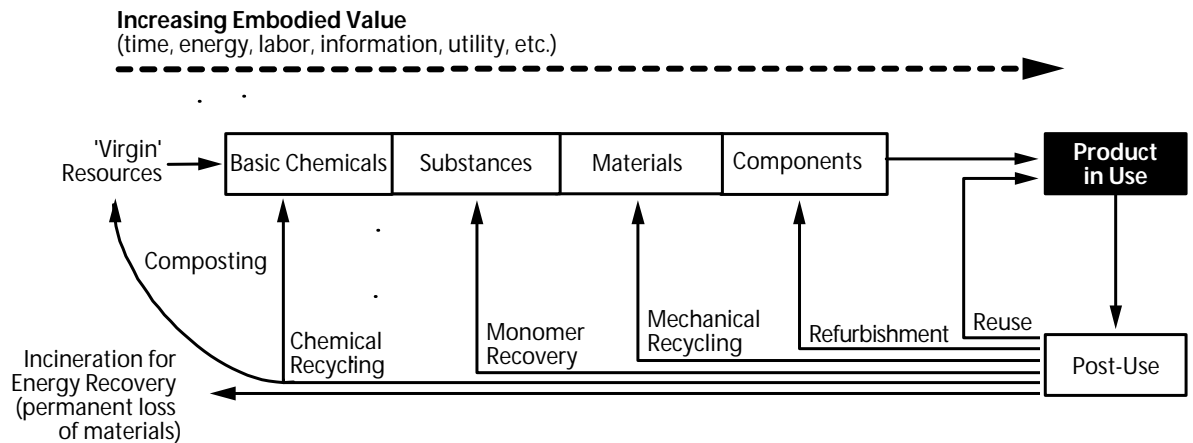
Technical metabolisms exist within the natural world and material releases to ecosystems are inevitable, technical nutrients ideally should pose little or no hazard to the biological metabolism. Lead is universally recognized as being so toxic that even minor releases damage human and ecological health. For car batteries there are safer alternatives (e.g., lithium, zinc) that provide comparable performance. Though these alternatives are currently more expensive, they do not carry the associated environmental and health costs of lead that we all currently subsidize. Cradle-to-cradle principles suggest replacing lead rather than simply optimizing the technical metabolism for lead acid batteries to reduce human and ecological impact.

Maximizing Value

Just as living organisms are more than simply the sum of their chemical composition, products have value beyond their simple nutrients or materials. For instance, a bicycle has utility beyond the value of its steel, aluminum, and rubber. Products embody the functionality and intelligence designed into them due to additive expenditures of labor, energy, and resources throughout the manufacturing process.

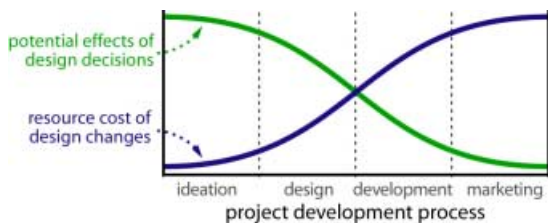
The degree to which value is added along the value chain of a product is largely a function of its materials and complexity. And while the opportunity to recover value occurs at various points along the value chain, economics and cradle-to-cradle principles advocate recovering value from a product at the highest level of embodied value possible. As shown in the illustration, reuse and refurbishment recover the highest level of embodied value by maintaining the primary function of the product. If the product cannot be reused or remanufactured, its materials are still valuable. With increased energy and labor input, its materials can be recovered either through recycling or composting.

For example, a bike is refurbished multiple times through replacing tires, chains, etc. – always maintaining its primary function. At the end of its useful life, the bike is fully disassembled and materials recovered through recycling.²



III. Practicing Cradle to Cradle Design

The greatest potential for realizing the positive benefits of Cradle to Cradle Design is in the early design phases of any given project, when opportunities to affect the outcome are greatest and the resources committed to a solution are smallest. Ideally, designers should take into account all material inputs and life cycle characteristics when redesigning an existing product or developing a new one.



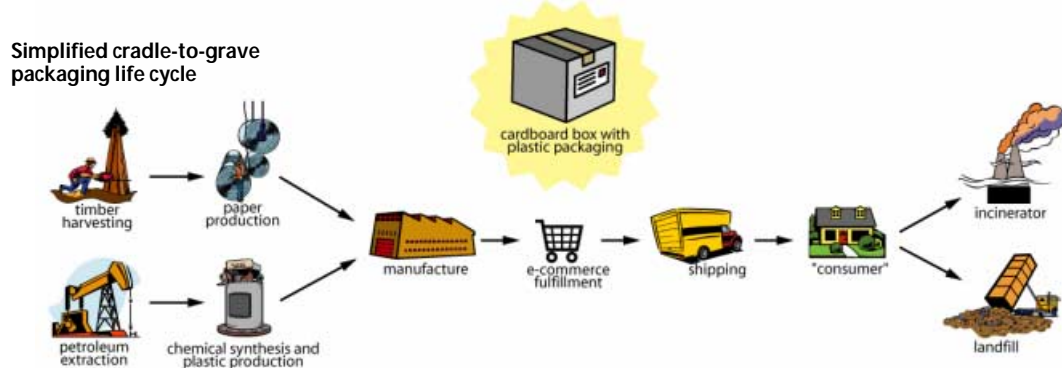
Fundamental to this design process is understanding how a material or product flows through its various life cycle stages (raw materials extraction and production, manufacturing, use, and recovery/reutilization). This provides a context to understand its impacts on human health and the environment. Life cycle thinking informs the decision-making processes involved in intelligent design by extending the design objectives to include post-use value recovery, and the human and environmental safety of materials.

Applying cradle-to-cradle principles, while challenging, can be energizing, allowing companies to envision materials as assets and create new market opportunities that are not available within the current take-make-waste system. By redefining the boundaries of design, purchasing, manufacturing, sales and product ownership, a company can begin to understand the business opportunities and reduced liability benefits. Given the limitations of current materials and technologies, it is not always possible to design a product or system that fully embodies cradle-to-cradle principles in the short term. However, design is a dynamic endeavor. Cradle to Cradle Design provides the long term vision for guiding the transitional steps to safer and more effective industrial design.

² The value recovery hierarchy is an accepted principle of industrial ecology and design for environment. It has been presented in a variety of texts including: Graedel, T.E. and Allenby, B.R. 1995. Industrial Ecology. New Jersey: Prentice Hall. p. 262.

IV. Cradle-to-Cradle Design Considerations for Packaging and Logistics

Currently, the life cycle of most e-commerce shipping packaging is best described by the one-way, cradle-to-grave model. The typical life cycle for an e-commerce package made from corrugated paperboard and plastic is depicted in the diagram below.

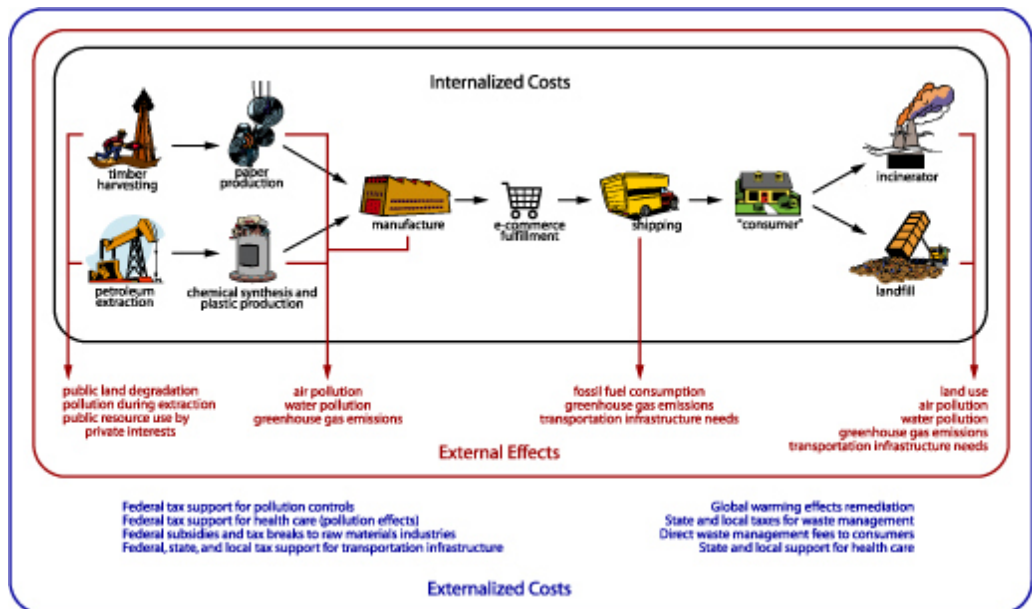


Several factors related to the system, package design, and consumer behavior contribute to the existing cradle-to-grave material flows.

System Design Considerations

In today's cradle-to-grave life cycle, external costs to consumers associated with raw material extraction, consumption of non-renewable resources, and various environmental and social impacts are not reflected in the cost of packaging. For instance, timber harvesting is occurring on public lands, trash disposal is subsidized by state and local taxes, and programs to remediate unintended environmental impacts including air and water pollution are paid for using tax dollars. As consumers, we typically do not think about these indirect financial costs of a product. Similarly, we typically do not think about the human health or environmental impacts of packaging that can be direct or indirect and are distributed over its life cycle.

External costs and effects associated with a cradle-to-grave life cycle



One of the advantages of cradle-to-cradle thinking is that the “true cost” or life cycle costs and impacts of the materials and associated systems for packaging can be identified and used to inform both the design and business processes. In turn, this presents an opportunity for designers to develop better products and for business to capitalize on the increased knowledge about their products and systems.

In dollar terms, packaging materials are not expensive. The function that packaging performs, protecting more valuable products from damage is the perceived “value” of packaging. As such, once packaging has performed its function, it is commonly considered waste both by consumers and businesses, instead of a resource and/or a business opportunity.

One of the goals of this design challenge is to change this perception by expanding the concept of value beyond function, through a shift from cradle-to-grave to cradle-to-cradle thinking. Currently, public perception of the environmental impacts of packaging focuses on the persistence of plastics in landfills, rather than the environmental and social impacts of raw material extraction, manufacturing and transporting packaging to and from consumers, or the local to global issues associated with landfills, incinerators and their emissions.

Some consider the relative value of packaging material to the cost of shipping a barrier to economically viable recovery schemes. Some of the questions to consider that challenge this might include:

- Are there costs associated with empty delivery or mail trucks on a return route?
- Is there a business opportunity to fill them with used packaging?
- What is the cost savings associated with reusing a box?
- What are the raw material cost savings to a paper mill or plastic processor to use recovered corrugated paperboard or plastic?

For the successful cradle-to-cradle flow of packaging, not only does there need to be a change in perception about the “value” of packaging once it has performed its function, but additionally there needs to be development of a recovery system to gather used packaging and stage it for reuse or recycling.

Any effective recovery system should be a value adding process. Economic, or other incentives can be designed to facilitate the return of used packaging from end users. Currently, there are few to no such incentives. Another characteristic of a successful recovery system is coordination of participants in the recovery chain and workable business models for each. An example of this is the well-developed system of reverse logistics for product returns associated with e-commerce. From the Internet retailers through parcel delivery entities, there is a well-coordinated system of reverse logistics in place for product returns. These existing systems may provide templates for effective packaging recovery as part of a cradle-to-cradle design.

Consumer Behavior

Consumer behavior is an important consideration for the cradle-to-cradle design of packaging and related systems. A well-designed package needs a complementary system that makes it as easy as possible for the consumer to recycle or compost the package.

Some questions to consider related consumer behavior include:

- What economic or other incentives might encourage consumers to recycle packaging?
- How easy is it for consumers to disassemble and store packaging?
- How far will consumers travel to recycle or compost packaging?

Additional benefits from Cradle to Cradle Design might include:

- development of a company policy with regards to materials selection and purchasing decisions
- improved communication about environmental aspects of product
- informed basis for product and process improvements
- opportunity for new business strategies
- improved corporate relations
- decreased costs through reuse and recycling of packaging
- new relationship with the customer that encourages repeat business (ex. discount on next purchase when packaging is returned).

Packaging Design Considerations

The ideal cradle-to-cradle packaging product is designed so that all of its materials are selected to safely cycle within either a biological or technical metabolism and to be reused or recovered at their highest possible value.

Material selection is an essential part in the development of a cradle-to-cradle product. A designer needs to understand the human and ecological health characteristics of the materials under consideration. Obviously, material science and toxicology are not the milieu of most designers. However, increasingly there are LCA—based resources available to designers that condense human health, ecological health (eco-toxicity) and energy data by material. (See resource list on website)

Material Safety

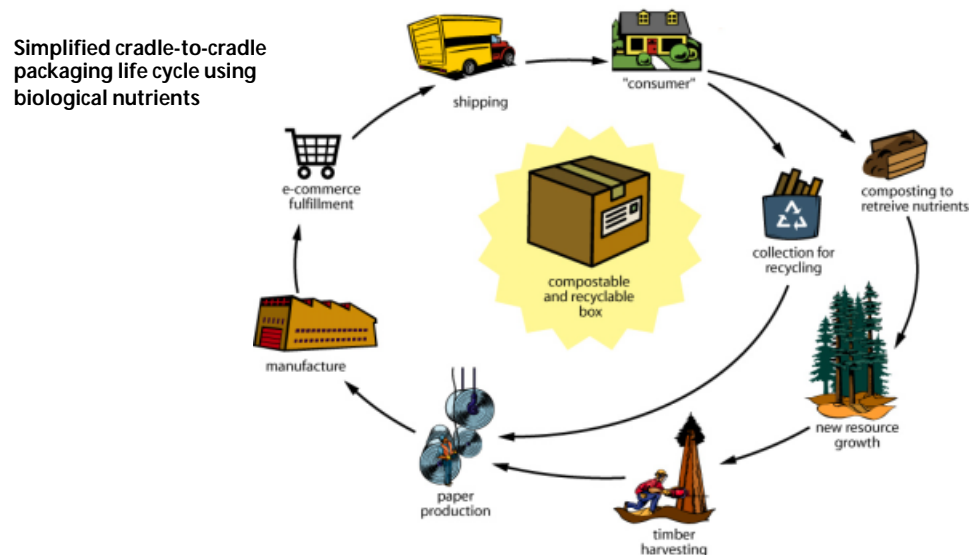
Materials can be assessed to ensure they are safe at each point of their life cycles. A material's impact on human and ecological health can be determined by characterizing materials through their entire life cycles, for impacts in four basic types of effects:

- Exposed organisms (carcinogenicity; endocrine disruption; irritation of skin/mucous membranes; sensitization)
- The succession of generations (mutagenicity, either accidental or engineered; reproductive and developmental toxicity; persistence/biodegradation)
- Food chains (bioaccumulation potential)
- Natural systems equilibrium (global warming and ozone depletion potential)

As much as possible, materials should be chosen that do not pose a risk, regardless of how they are used. Consumers often do not use the product as the designer intended. For example, many still burn their trash even though it is illegal.

Additionally, a designer needs a general understanding about the origin and fate of materials and their environmental impacts, within the context of the current life cycle. This provides a basis for assessing the impact of design modifications and for understanding the metabolism one is designing for in a cradle-to-cradle system. For instance, if one is designing packaging that would ideally flow in a biological metabolism (i.e. a managed composting system), the palette of materials under consideration must be appropriate for that metabolism. Materials that are biodegradable and safe for human and environmental health (biological nutrients) are appropriate for biological metabolisms.

The diagram below depicts a corrugated paperboard package designed as a biological nutrient.



Because it is biodegradable, corrugated paperboard packaging is suitable as a biological nutrient as long as the human and ecological health characteristics of all its materials, including the inks, adhesives and labels, are biologically suitable and safe to return to natural systems.³ However, the raw material for virgin paper, trees, takes decades to grow. Does it make sense to use a box once and return it to soil when it takes 25 years for a new tree to grow to replace the raw material? As a result, there are temporal considerations associated with the suitability of a material when designing for the biological metabolism.

In contrast, some current designs of packaging are hybrids, where materials appropriate for technical and biological metabolisms are used together. For instance, a non-degradable HDPE plastic shipping label that cannot be easily removed from a paperboard box, poses a problem for a managed composting systems.

If the labels can be easily removed from the box then the hybrid design is appropriate as long as all materials are safe, and systems exist for their recovery. Extra effort is required to ensure that labels are removed so that neither the biological or technical metabolism is contaminated.

³ For more information on designing a package for a biological metabolism, refer to EUROPEAN's report, [Understanding the CEN Standards on Packaging and the Environment: Some Questions and Answers](#) for a description of the EU CEN Standard on the Organic Recovery of Packaging (EN 13432:2000).

Cradle-to-cradle e-commerce packaging could also be made of technical nutrients that cycle in a technical metabolism. An example of packaging designed as a technical nutrient is depicted below. Plastic packaging is suitable as a technical nutrient if: 1) all of its materials, including the plastic, inks, and adhesives, are safe for human and ecological health at each point of the life cycle; and 2) it can be recycled again and again, maintaining its optimum material value.^{4,5}

Simplified cradle-to-cradle packaging life cycle using technical nutrients



Even though packaging materials may be safe to return to nature from a human and ecological health point of view, if the system or infrastructure doesn't exist to recover value, not only is there loss of material and embodied utility, but these losses may have unintended impacts on the environment and human health (i.e. release of methane from anaerobic decay in a landfill).

The ideal cradle-to-cradle scenario allows the packaging to be reused. Reuse recovers materials and product utility at its highest possible value.⁶ However, after one or several cycles of use, physical wear and tear will take its toll on almost any material. The issue becomes, at what level material value can be recovered now that the utility of the package is lost and what system is needed to achieve it. For corrugated paperboard or plastic, this is generally recycling – value is recovered in a technical system.

Another possible scenario for corrugated paperboard is the recovery of its nutrient value through managed composting – value is recovered through the biological system.

Cradle to Cradle Design Objectives and Guidelines

Cradle-to-cradle principles expand the design objectives and the arena for evaluating effective e-commerce packaging. By adding *recovery of healthy materials at their highest level of value* to traditional *cost* and *performance* design objectives, Cradle to Cradle Design extends the design focus to include post-use systems, and brings to the front the environmental and human health characteristics of materials.

Below is a list of traditional performance considerations and the additional cradle-to-cradle guidelines by major decision area.

⁴ For more information on designing a package for a technical metabolism, refer to EUROPEN's report, [Understanding the CEN Standards on Packaging and the Environment: Some Questions and Answers](#) for a description of the EU CEN Standard on Material Recycling (EN 13430:2000).

⁵ Plastic, in most cases, is considered a technical nutrient. However, with the development of biopolymers and synthetic polymers designed to biodegrade, the value of selected plastics can be recovered through biological or technical metabolisms.

⁶ For more information on designing a package for reuse, refer to EUROPEN's report, [Understanding the CEN Standards on Packaging and the Environment: Some Questions and Answers](#) for a description of the EU CEN Standard on Reusable Packaging (EN 13429:2000).

Cradle-to-Cradle Design Guidelines				
Performance⁷	Materials	Physical Design	System	Economics and Marketing
<ul style="list-style-type: none"> • Does the packaging meet ISTA 3C, or ASTM D4169, or ISTA 1A standards? • Can the packaging be used in high speed sorting systems? • Is it compatible for use in existing air and ground transportation logistics systems? • Are strength requirements met? • Does the form of the package meet the standard shipping requirements for the type of load? • Does the packaging brace or block the item in position to eliminate movement within the container? • Does the packaging protect the item's surface from abrasion, scratching, etc? • Does the package provide protection from the environment (i.e. moisture)? 	<ul style="list-style-type: none"> • Are the materials biological or technical nutrients? • Are all of the material inputs known (e.g., major components, as well as inks and adhesives)? • Are the materials safe for biological systems at all phases of the life cycle? • Are the materials reusable or recyclable at a high level of value? • How energy intensive are the selected materials? • Are materials containing recycled content available for use that meet performance and human and environmental health criteria? 	<ul style="list-style-type: none"> • Has the product been designed for easy and effective reuse, disassembly, recycling or composting? • Are components identified by material for recyclability? • Was transportation energy evaluated as part of package design? (e.g., light-weighting) • Has the product been designed to optimize material use (use as little material as possible by volume and weight)? 	<ul style="list-style-type: none"> • What is the existing life cycle of this type of product? • Are you designing for the existing metabolism (life cycle), for an optimized metabolism, or for something entirely different? • What are the post-use take-back and recovery mechanisms of the metabolism? • What is the ideal cradle-to-cradle post use scenario for this product? • Are components identified for sorting and recyclability? • Are you designing for a technical or biological metabolism, or for both? 	<ul style="list-style-type: none"> • What is the cost of a cradle-to-cradle package? • What are the initial and ongoing costs and savings associated with the cradle-to-cradle packaging and packaging system? • Are there economic incentives for a cradle-to-cradle solution? • What external costs are eliminated by a cradle-to-cradle solution?

⁷ Performance criteria are based on guidelines provided by the Institute of Packaging Professionals, Guide to Packaging for Small Parcels (http://www.iopp.org/files/Small_parcel_shipping_guidelines.pdf, accessed on Sept. 2002).