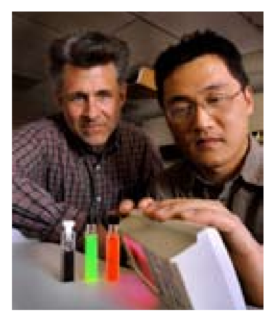
Better by Design

An Innovation Guide: Using Natural Design Solutions







Design *for the* Environment

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Jay Harman, Pax Scientific, is applying the spiraling geometric pattern found in shells, galaxies, and whirlpools in drains to design very efficient pumps and fans.

Introduction

As founder of Pax Scientific, Jay Harman has a long-time interest in spiral or vortex flows found in nature. After studying them for over 20 years, he created an exhaust fan that is half as noisy and three-quarters more energy efficient. He based his design on the same "three-dimensional centripetal spiral" flow design that is found on the inside of nautilus sea shells. This same design shape, based on the basic math formula known as the Fibonacci series, is in fact used throughout the natural world where optimal flow is needed.

Design + environment

Why look to nature for design? After 3.8 billion years of selecting what works and what doesn't work, nature has already selected the most optimal way to move fluids. Pax Scientific of Perth, Australia, continues to use what they have learned to design exceptionally efficient industrial mixers, automotive cooling systems, water pumps, marine propellers, and devices for circulating blood.

This is just one success story of many from companies that are beginning to tap into nature's vast source of proven research. Janine Benyus captured the essence of this new science in her book, *Biomimicry, Innovation Inspired by Nature.* She writes of quieting our urge to quickly go to an answer but rather to listen and allow the genius of nature to lead us to solutions. Nature's solutions are not only optimal in design, they are also always based upon life-sustaining principles.

The key is to envision nature as a teacher, a partner in emerging technology, to build effective design solutions that are also compatible with life. There is much to learn. Much of traditional manufacturing has been based upon "heat, beat, and treat" processes. In contrast, Jeff Brinker of the Sandia National Laboratories is researching abalone shell formation, which occurs in water at low temperatures through self-assembly for non-polluting, efficient production of nano-composites.

Re-invent design

This guide contains a set of skills that will allow you to re-invent yourself as a designer and your products. It offers a simple, systematic way to weave environmental considerations into product design (design for the environment), while using inspiration from our natural world to optimize and distinguish your designs.

Design: A powerful stage

Design is key to the function, meaning, and appeal of products used by people every day throughout the world. It has long been recognized as a critical stage for determining costs and profitability. The National Research Council estimates that 70 percent or more of the costs of product development, manufacture, and use are determined during initial design stages. For those who bring shape to our physical world by designing products, it is also an unparalleled window of opportunity to distinguish products, while championing the environment through innovation.

Exactly what draws consumers to pick up a product or just to want it is sometimes referred to as "Factor X." While this factor can be elusive, a common element of good design is satisfaction of the core needs of the user. Meeting these needs with unique, improved design differentiates products in the marketplace.

A way to drive design that differentiates products is by adding or integrating natural design elements into a current product design process through the use of design for the environment (DfE). DfE is based upon consideration of the entire lifecycle of a product "upfront" during design. This unique perspective reveals new windows of opportunity for optimizing designs, to simultaneously improve product function and appeal along with efficient use of materials and energy.

A number of leading companies—Xerox, IBM, Volvo, Sony, Ford Motor Company, Toyota, Philips, AT&T, Nokia, and many others—recognize multiple benefits from integrating DfE into their product design processes, including:

- Innovative, optimized product design
- Reduced costs (efficient use of materials, energy)
- Reduced manufacturing cycle times
- Improved sales and marketing position
- Reduced regulatory concerns

Integrating DfE into product design is an emerging trend, essential for manufacturers who wish to distinguish themselves through design excellence in the global marketplace. When social along with environmental and economic impacts are considered, it is called design for sustainability (DfS or D4S).

What is Design for the Environment?

Design for the environment, sometimes called ecodesign or green design, is a systematic way of considering the entire life or life cycle of a product up front, during design. When social along with environmental and economic impacts are considered, this approach is called design for sustainability (DfS or D4S).

From the life-cycle perspective, designers gain inherent drivers for improving design. Materials tend to be selected more prudently and used more efficiently. Consideration of alternative materials or sources of energy is built into the design process. The result could be an ingenious connector design or use of a small fuel cell for energy.

These product features, which reduce the environmental impacts of the product for its entire lifecycle, often distinguish products, generate significant cost savings through reduction of waste, and facilitate manufacturing processes.

"The core idea is that nature, imaginative by necessity, has already solved many of the problems we are grappling with. Animals, plants, and microbes are the consummate engineers. They have found what works, what is appropriate, and most important, what lasts here on Earth. This is the real news of biomimicry: After 3.8 billion years of research and development, failures are fossils, and what surrounds us is the secret to survival."

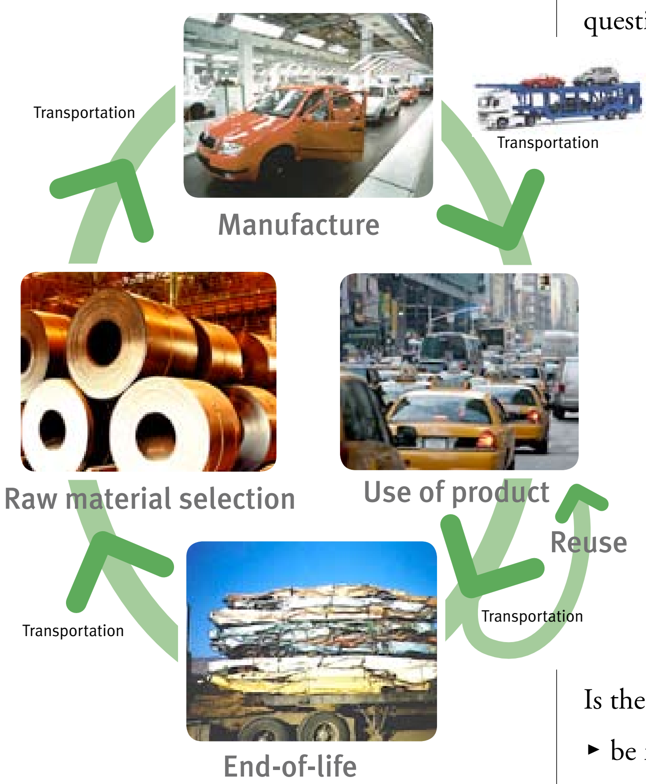
— Janine M. Benyus, author *Biomimicry: Innovation Inspired by Nature*

Innovative fasteners | The acoustic foam on this IBM computer panel is attached with dart-shaped connectors to securely hold the foam in place without use of a chemical adhesive. This simple, yet ingenious connector also makes it easy to separate these materials for recycling at the end of the product's life.

"Design for the environment surprisingly coincides very well with design for manufacturability. (With) design for the environment, we have a lot of components and pieces of the hardware that snap together or can come apart easily, and that also benefits our manufacturing assembly time as well as the throughput rate of all of our products on the production floor. So not only do we get the environmental benefits, but we get the manufacturing benefits at the same time."

— Greg Vande Corput, Hardware Development Engineer, IBM (Better by Design video, 2004)

Innovation: A Life-cycle Perspective



Each life-cycle stage of a product (materials selection, manufacturing, use, end of life) introduces opportunities to design in new types of alternative materials, fasteners, optimal shapes, or renewable power. DfE checklist questions listed for each life-cycle stage can guide exploration of these options. (See sample DfE checklist on page 15.) The resulting decisions, based upon the environmental impacts of the product, most often complement or even enhance other considerations such as customer appeal, safety, time to market, cost reduction, and manufacturability.

DfE is not a stand-alone process; rather it is integrated to enhance a current design process. Integration can be as basic as adding a checklist of key questions that cover the entire life cycle of the product to give the design team a holistic perspective. These questions also serve as a springboard for discussion and generation of new ideas.

Materials selection

During this stage, the raw materials and parts used in a product are selected, then procured. This stage offers a window to consider a vast array of innovative options, such as the wide variety of plant or bio-based materials (including plastics) available for use in products (see Appendix D, page 27).

Is the product designed to:

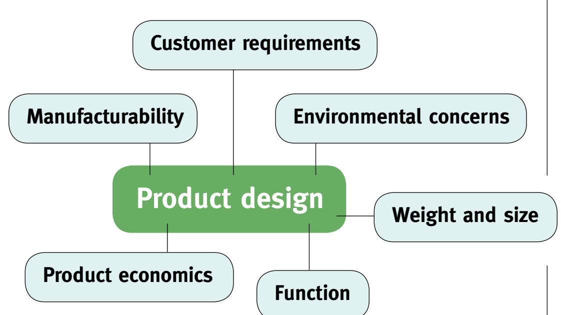
- be made from recycled, recyclable, or compostable materials?
- avoid or minimize the use of restricted or hazardous materials contained in the product?
- minimize the number and types of materials contained in the product?
- if plastics are used, are they clearly marked by an identification system such as ISO 11469?

Survey your suppliers

It is increasingly important to determine the exact composition of raw materials and parts that will be used in a product. Companies are now surveying raw materials and parts suppliers to avoid any material composition surprises. This prevents problems when marketing products to customers with specific materials requirements while complying with a number of international regulations related to restrictions on use of certain materials (see Appendix A, page 24).

For example, a yellow pigment may be enhanced by the addition of cadmium. Hexavalent chromium, a restricted use material in some countries, could be used to coat metal parts to prevent corrosion. If these materials are not declared by the suppliers, the recipient manufacturer could unknowingly be using materials it wants to avoid. In this case, the manufacturer may want to work with its suppliers to explore viable alternatives. Several DfE software programs that compare environmental impacts of various materials can also aid in selecting and sourcing preferable materials (see Software tools, page 23).

Considerations such as safety, costs, time to market, manufacturability, weight, size, and color, along with environmental attributes are all significant, interconnected aspects of product design. DfE is integrated into existing product design processes.



Surveying suppliers can also provide information about other environmental impacts such as water and energy use at a supplier's facility during preparation of the raw materials or parts. Simply asking, "Do you have an environmental management system (EMS) in place?" gives an overall indication of commitment to the environment and continual improvement. If a first-tier supplier surveys a second-tier supplier, who then surveys a third-tier and so on, a cascading effect with a broad influence can occur.

Manufacturing

For this life-cycle stage, recognizing the varying needs of design team members representing various departments in a manufacturing facility is key. For example, the production department's performance may be measured on how many products are produced within a certain time period (manufacturing cycle time). A research and development department (R&D) may be interested in containing the level of cost per unit. Representatives of the marketing department will want to use environmental improvements as selling points to customers. Often improving the environmental attributes of a product will address these various concerns simultaneously. Responding to the needs and the focus of various departments, with proposed improvements, can build the support needed for design changes (Medtronic, Inc. case study DfE Guide Sheets).

As in nature, a basic objective of any product design should be to minimize the number and types of manufacturing process steps used — to simplify. Each additional manufacturing step creates an opportunity for errors that can generate waste and cost.

Is the product designed to?

- avoid the need for using hazardous or restricted materials during the manufacturing process?
- optimize assembly during the manufacturing process (relates directly to disassembly)?
- avoid energy-intensive processes during manufacture (for example, multiple heating or cooling cycles)?
- minimize waste during the manufacturing process (avoiding surplus coating, cut-aways, trimming, by-products)?

Product use

During this stage, a product performs a service or function for the user. Some companies have begun basing their marketing on providing a service or function — not selling a product. Xerox was one of the first to successfully market this idea: selling copying services through lease of their copiers. The copiers continue to be owned by Xerox, where they are refurbished for reuse, upgraded, or recycled as part of a closed-loop system. This avoids disposal of the copiers in the waste system when they are no longer useable by the customer. Interface, a commercial flooring manufacturer, leases carpeting and other flooring to businesses as part of a closed-loop system where the flooring materials are recovered for recycling.

Is the product designed to:

- be easily disassembled for repair, upgrade, or reuse?

Continued on page 7.

Blankets made from Ingeo, a naturally derived fiber, at the Faribault Woolen Mills, (Faribault, Minnesota).

Project Ingeo

Faribault Mills began looking for innovative, environmentally friendly fibers for making blankets to substitute for man-made synthetics, which use non-renewable resources and do not break down in landfills. The answer was Ingeo, a naturally derived fiber from corn, manufactured by Dow. The process for making the fiber is based upon a natural process — fermentation of simple plant sugars from corn, which creates a polymer that is in turn spun into a fiber. Faribault Mills finds Ingeo to be economically and environmentally sustainable, with superior performance characteristics. Blankets made from this material are recyclable or biodegradable at the end of usefulness.

www.moea.state.mn.us/p2/govaward04.cfm

These Toyota floor mats are made from bioplastics.

Bioplastics

Toyota is now using bioplastics for car floor mats and the spare tire cover in some of its cars. Bioplastics are derived from agricultural products such as sugar cane, corn, and tapioca. The Toyota biotechnology division is working with some 60 companies, including office equipment makers such as Fujitsu and NEC, to supply them with bioplastics.

www.toyota.co.jp/en/more_than_cars/bio_afforest/satsumaimo.html

Power for Products

With the decrease in power requirements for portable consumer electronics comes a number of options for clean sources of energy. Small fuel cells, thermic power (from human body heat), advanced wind-up, kinetic, and piezo effect electricity from crystals are all potential sources of power from renewable sources currently being researched for consumer products.

This Nightstar flashlight uses renewable, human power to produce electricity that powers an LED light source.

Human-powered flashlight Inside the Nightstar flashlight, developed by Applied Innovative Technologies, Inc., a high-strength rare earth magnet passes smoothly over a wire coil when gently shaken. This generates electricity that is stored in a rechargeable, heavy-duty capacitor. The electricity powers a super-bright, light-emitting diode (LED) that has a lifetime of tens of thousands of hours. www.nightstarflashlight.com

Fuel-Cell Motorbike The ENV bike (emissions neutral vehicle) is powered by a small fuel cell that uses hydrogen to produce electrical power. This nearly silent motorbike reaches 50 miles per hour, runs for 100 miles before refueling, and emits only water vapor. Intelligent Energy, the manufacturer, also makes technologies that separate hydrogen from other fuels for use in the ENV motorbike. www.intelligent-energy.com

Walking watts A new backpack, developed at the University of Pennsylvania, generates electricity as you walk. Designed to help soldiers and emergency responders, the backpack puts out up to 7.4 watts, enough to power a head lamp, a phone, and global positioning system. It has a rigid frame like a hiking pack, but the bag itself is fastened to springs and slides along a track. As the carrier walks, the load rises and falls a few inches, driving gears connected to an electrical generator.

A green-toothed rack inside the backpack moves up and down, causing the gear mounted on the electrical generator to turn and generate electricity.

Renewable Packaging & Transport

A number of packaging options that use renewable materials are available. Polylactide (PLA) is a polymer produced by Cargill Dow from lactic acid derived from cornstarch dextrose through fermentation. This biodegradable material is currently used to make clear food clam-shells, trays, dairy containers, consumer and electronics packaging, cold-drink cups, shrink wrap, and windows for envelopes.

Currently most PLA is made from corn, but Cargill Dow is also working on using corn stover (residue left in the fields), grasses, wheat, rice straw, and sugar cane residue. At the end of usefulness, packaging made from this material can be composted along with food waste.

www.natureworksllc.com

BIOTA bottles made from PLA by NatureWorks compost in about 80 days in a commercial composting facility.

This deli salad container is made from compostable PLA.

Continued from page 5.

- avoid disposable components such as one-time use cartridges, containers, or batteries?

For products requiring a power source, is the product designed to:

- use electric power efficiently or use renewable energy?
- use batteries that are easily identifiable by type and are removable?

Transport & packaging

Reducing the impacts and costs of distribution and packaging supports all of the life-cycle stages of a product.

Is the product designed to:

- reduce the need for protection with packaging when possible?
- use packaging that contains recycled content or compostable materials?
- avoid the use of restricted or hazardous materials in inks, pigments, and materials used to package the product?
- use reusable transport packaging when possible?

End of product life

A goal for this stage is to make reuse or recycling of products easier, so recovered materials can be used as resources rather then end up as costly wastes. Design for disassembly (DfD) allows products to be easily taken apart for reuse or recycling of components and materials.

Is the product designed to:

- be easily disassembled so that components can be reused, recycled, or composted at the end of product life?
- be made of materials that are labeled, are easy to identify by type, and are easy to separate?
- avoid special handling materials or components at the end of product life because none of the materials used are on your customer's restricted use list or are hazardous?

3M Stretchable tape

Alternatives to shrink-wrap

3M Stretchable Tape produces 95 percent less waste than conventional shrink wrap. By focusing on function, designers were able to develop an entirely new type of product to meet the same objective of pallet load stability, while significantly decreasing waste.

Lock n' Pop (Key Tech Corporation) is a water-based adhesive sprayed on the bottom and top of boxes to securely hold them in place in stacks on top of pallets. Once the pallet reaches its destination, the boxes are easily popped apart. The adhesive, described by the company as environmentally friendly, is also fully compatible with recycling of the cardboard boxes.

www.locknpop.com/index.html

End of product life: Design for disassembly

The Think® chair manufactured by Steelcase is 99 percent recyclable and can be disassembled by hand tools in 5 minutes so that components can be returned to the raw materials stream. The chair is expected to have a 20-year life expectancy that will likely be extended through office donations of the chairs to nonprofits, homes, and schools for a second life.

Steelcase considered the impact of the 14 raw materials used to manufacture the Think® chairs. After evaluating potential materials, only those that were at little, low, or moderate risk to humans and the environment were used. The chairs also contain 41 percent recycled-content materials and are often shipped to customers in reusable totes rather than cardboard boxes. As part of their focus on sustainability, the company launched the Steelcase Environmental Partnership to help customers determine the most environmentally responsible way to manage any Steelcase furniture at the end of its usefulness. www.steelcase.com/

Inspiration from Nature

Considering the entire lifecycle of a product during design mimics the cycle of use and reuse of all materials found in the natural world. In addition to this core design principle, other natural attributes can optimize and bring distinction to the design of products.

This dirt resistant paint manufactured by Lotusan was designed after the natural self-cleaning mechanism of the lotus flower. www.lotusan.de/lotusan/_04_faq/index.jsp

As rain water hits the rough surface of a lotus flower, it runs off in small beads, taking any dirt with it. Discovery of this ingenious, natural self-cleaning mechanism, known as the "lotus effect," has led to its use in house paint, tiles, and window glass panes. Lotusan™ paint is one such product that keeps surfaces dryer, cleaner, and saves on the need for repair.

From a laboratory in the U.K. comes a biomedical product, inspired by the tolerance of lichen plants for "wetting and drying" cycles. Using what they learned from the plants, researchers at Cambridge Biostability developed a dehydrated vaccine for immunizing children in countries where refrigeration is not readily available. In addition to a long shelf life, no preservative additives such as mercury compounds are needed in these vaccines.

Nature's design principles

These are but two examples from the vast spectrum of opportunities for design solutions that nature offers from its wealth of 3.8 billion years of proven research on what works, what doesn't work, and what is life sustaining. "We have only begun to tap into its genius. "…nature, imaginative by necessity, has already solved many of the problems we are grappling with," explains Janine Benyus, author of *Biomimicry: Innovation Inspired by Nature*. To follow are some of the biomimicry design examples she and Dayna Baumeister of the Biomimicry Guild have begun to compile for a database that will serve as a resource for product designers.

http://database.biomimicry.org/

Form fits function

Nature optimizes rather than maximizes. One of nature's fundamental design principles is optimizing shape or form to best suit or fit the function. The reason is efficiency; shape is less expensive than material.

Coloration by light

Many colors in nature result from light reflecting off structures, not the use of pigments. Often this can be seen in bird feathers or butterfly wings when light reflects and scatters off thin layers of cells.

A Japanese manufacturer, D-Tex, has made use of this natural design feature to colorize a fabric called Morphotex™. The fabric's color comes from 61 layers designed to mimic the natural structural color of the wings of a South American butterfly. This technique has the potential to create intense coloration without chemicals or the addition of heavy metals such as cadmium or chromium.

Swim like a fish

Taking inspiration from nature, the Speedo Fastskin swimsuit mimics a shark's skin, significantly reducing water drag. At the Sydney Olympics in 2000, 28 of the

33 gold metals were won by swimmers wearing this suit, which continued to be worn by competitors during the 2004 Olympic competition.

www.worldwideaquatics.com/Fastskin.htm

Better way to climb mountains

After studying the woodpecker's ability to chisel tree wood through 25 forceful hits per second, designer Franco Lodato designed a better ice pick axe for mountain climbers. He noted that the woodpecker's entire body is designed to support this movement. The birds brace themselves with their tails, which functions as a spring, as the skull bone structure absorbs stress (the hammering does not result from use of their necks). The ice pick axe has an inner core of titanium into which an adjustable aluminum point is attached by a hinge (inspired by the valves of a mollusk). The handle has a slight curve, mirroring the body shape of the woodpecker. http://www.dmi.org.

Self-assembly

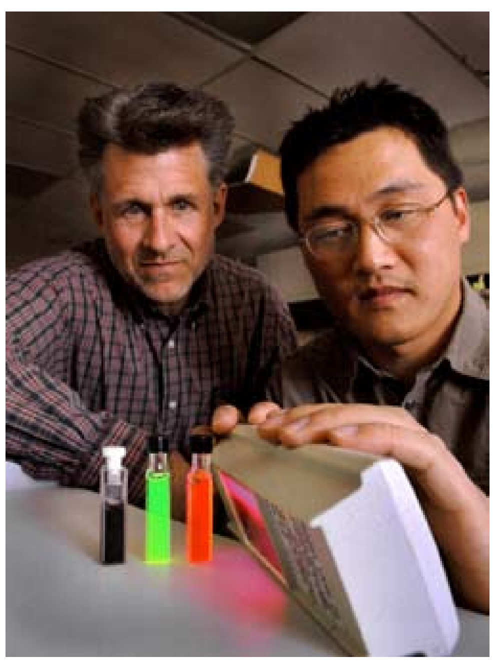
What if materials could self assemble at low temperatures without the use of toxic materials? Materials could be created in relatively passive processes with minimal energy. The natural world provides examples of just how this is done.

Leading edge inspiration: Nanotechnology

Jeff Brinker at Sandia National Labs mimicked the self-assembly process of the abalone shell to create rapid self-assembly of nanocrystal arrays in water at low temperatures. His discovery solved a number of problems that had continued to puzzle materials scientists.

The resulting arrays (each nanocrystal is separated by silicon dioxide), which can carry electrical current, are key to development of nano-electronic devices for treatment of disease. Because of their characteristics, the arrays are useful for biosensing or locating, then biolabeling targets like cancer cells. In addition, the array material can be used for general memory storage in nano-electronic devices and mechanical, thermal, chemical stress detectors.

This discovery has greatly advanced the production of nanostructure arrays in a preferred hard, protective structure using low temperature, aqueous self-assembly. The entire production process is compatible with the life-sustaining principles of nature.



Biofeedback

Feedback loops, prevalent in nature, allow organisms to communicate when and how to react to make the most of their habitat and resources. The natural feedback mechanisms are being mimicked to create more effective, nontoxic products.

Olympic Gold Medalist Natalie Coughlin in a Speedo Fastskin FSII swimsuit, which mimics a shark's skin, significantly reducing water drag.

Jeff Brinker (left) and Hongyou Fan observe nanocrystals self-assemble in water. The process mimics low-temperature, self-assembly mechanisms used by abalone shells and other marine organisms.

http://www.sandia.gov/news-center/news-releases/2004/micro-nano/nanotoolcase.html

The Entropy carpet tile mimics the random pattern of a forest floor.

Biologists at the design table

Interface, the world's largest manufacturer of commercial carpet, worked with biologist Dayna Baumeister of the Biomimicry Guild during the design of Entropy carpet. The concept came during an exploratory walk the design team took in a forest. The result was use of a random, disorder built-in pattern that mimics that of a forest floor. Made from recyclable nylon, using a single dye lot that has 48 different color ways, the Entropy carpet has become one of the company's bestselling designs.

Entropy carpet tiles can be moved anywhere, face any direction; if a carpet tile wears out in a high traffic area or gets stained, it can be readily replaced. The randomness hides any evidence that older tiles are among newer ones.

www.interfaceflooring.com/sustain/seven.html

Biosignals to control pathogens

An Australian seaweed may hold the answer to solving a long-standing, critical medical problem: the formation of biofilms. These films of bacteria, which tend to be antibiotic resistant, form on catheters, implants, hospital equipment, and in the lungs of cystic fibrosis patients.

The seaweed counters the bacteria's ability to produce biofilms by using furanone, a substance that interferes with bacteria signaling mechanisms. Blocking the ability to sense signals prevents the bacteria from cooperating as a community to form a biofilm.

Biosignal Ltd, an Australian manufacturer, is using knowledge gained from seaweed, to produce synthetic furanones that will used to inhibit biofilm formation on medical devices, lungs, skin, teeth, membranes, pipes, and ship hulls.

Patterns in nature

Natural patterns are an intriguing area of study that can offer insight for design solutions. The Fibonacci series is not only the mathematical basis for the nautilus's three-dimensional centripetal spiral form, but it is also used in the arrangement of petals on flowers and the spiral arrangement of seeds on flower heads to maximize the number of seeds contained in a limited space. This optimized arrangement of seeds, could provide answers to a packaging designer who is attempting to maximize amount of product per available space. (See Sources of Additional Information, page 30, for a list of books on this topic.)

Building a business case

Integration of DfE into current product design processes can build a profitable niche for a product in the marketplace. It is a way to distinguish companies as leaders and innovators. For instance, Ford Motor Company has implemented what it calls "class-leading actions." One result is that all newly developed Ford vehicles are 85 percent recyclable, and contain 20 to 50 parts (air intake manifolds, insulation, carpets, etc.) made from recycled materials such as used bumpers, tires, plastic bottles, carpets, computer housings, and clothing. Companies are also benefiting in a variety of other ways from the use of DfE.

Cost savings

Significant cost savings can be realized by using DfE during design. This is most evident when changes are made during the materials selection and manufacturing life-cycle stages to optimize use of materials and select the least hazardous materials. Medtronic, Inc., a medical products manufacturer, used DfE to redesign an oxygenator, resulting in a 75 to 85 percent reduction in chemical use and wastewater loading, for an annual savings of $2.1 million (see DfE Guide Sheets: Medtronic Case Study).

Anticipate rather then react

DfE allows companies to anticipate rather than react to regulatory and market changes. As a result, companies such as IBM are prepared in advance for mandated restrictions on use of some materials in the international marketplace.

Continued on page 12.

Refrigerated deli display developed with DfE by Electrolux.

Design: Green & profitable

DfE software was used to improve the profitability of an Electrolux refrigerated display cabinet for supermarket delis by calculating the financial return at each stage of disassembly. Calculating end-of-life costs up front allowed the design team to compare disassembly costs with the recovery value of each part. This also guided designers to make the product upgradeable through replacement of modular subassemblies, eliminating the need for customers to replace the entire display cabinet.

Environmental impacts of commercial cooling displays are readily apparent. Typically they consume most of the energy used in supermarkets. They also require periodic styling updates even though many of the parts of the unit may still be fully functional. Electrolux developed a product that is cost effective and appealing to customers, yet meets environmental objectives. Through the use of DfE software, in consultation with TNO Industrial Technology (the Netherlands), the disassembly time of this product was reduced by 40 percent, with 96 percent of the materials recycled at end of life, and energy use reduced by about 10 percent.

How did the designers get these results?

- Silicon insulating strips were replaced with foam strips that can be peeled off during assembly (they also found this to be more aesthetic).
- Larger copper evaporators improved energy efficiency.
- Alternative materials were used to increase recyclability. For example, the polyester bin sections, traditionally filled with polyurethane, were replaced with a combination of recyclable surface, foam, and adhesive.
- The amount of copper and aluminum used in large parts was decreased, while the use of recycled materials was increased.
- A new support construction for the glass and lighting allows for rapid disassembly and conversion between serve-over and self-service displays.

To address the need to upgrade the style of an otherwise functioning refrigerated display, designers use modular subassemblies to ease disassembly and replacement. The Chameleon, Electrolux's new "green" refrigerated display, is marketed under a series of brand names such as Frigidaire and Kelvinator. www.dfma.com/news/Electrolux.htm

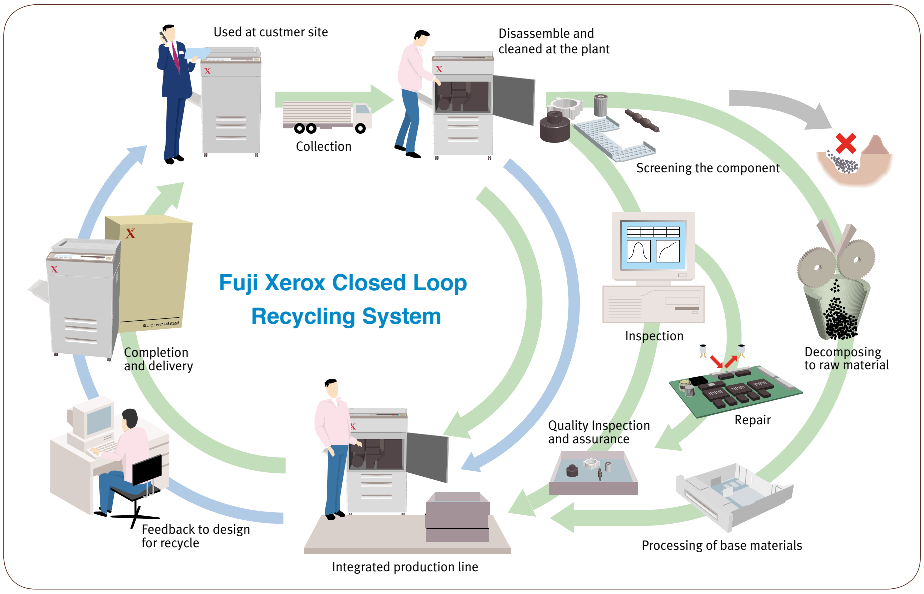
Hewlett Packard design saves costs

"...eliminating an adhesive that made it hard to recycle ink-jet cartridges ended up saving the company $2.4 million over two years, while eliminating unnecessary packaging on printer cartridges reduced production cost of each one by 17 cents. Last year, HP received more than $6 billion in bid requests that required information about its commitment to social and environmental responsibility – far more than it received the year before." – Sierra Magazine, July/August 2005, www.sierraclub.org/sierra/200507/gately.asp

Human-powered watercraft, such as the Escapade and Encore, are manufactured by Nauticraft, Inc.

Pedal-powered Nauticraft boats

Nauticraft Corporation (Muskegon, Michigan) manufactures new types of human-powered watercraft. Not only do these boats use only renewable energy (human pedal power), but the company's manufacturing process uses clean technology: "no hazardous pollutants are released into the atmosphere." The polyethylene material used in the boats is potentially recyclable for use in other products. In addition, "there are no loud annoying engine noises to disturb wildlife or neighbors, nor any smelly engine exhaust." www.pedalcraft.com



Continued from page 10.

For example, the restrictions in the European Union RoHS directive (Restriction of Certain Hazardous Substances, effective July 2006) set maximum levels for lead, cadmium, mercury, hexavalent chromium, polybrominated biphenyls (PBBs), and polybrominated diphenyl ethers (PBDEs) in some electronic products. Companies using DfE are already prepared for restrictions such as RoHS, preventing delays.

Life-Cycle Perspective: Fuji Xerox

Fuji Xerox uses life-cycle concepts to design copy machines with reuse and recycling in mind. Used products collected from customers are disassembled and cleaned, checked for quality, then reused. Materials from parts that cannot be reused are recycled for use in new components. The end result is a closed-loop system.

Some of the basic reuse/recycling design principles used to support the closed-loop system include creating parts that are:

- made for long life and reuse
- easy to separate or disassemble
- made of materials that can be readily recycled
- standardized with components common to existing and future models

Information gained in these closed-loop processes is used to further improve designs to increase reuse and recycling of parts.

www.fxap.com.sg/abouEnvt.jsp

Getting started: Use of DfE

A key to successful integration of DfE into current design steps or procedures is keep the process streamlined and practical to use. A cumbersome, complex DfE process that is separate from current procedures is unlikely to be used on a long-term basis. Companies with an environmental management system (ISO 14001) often integrate DfE into their system from the start or incorporate it later during a continual improvement review (see Appendix G, page 29). Whatever means are used to integrate DfE into design need to fit with the culture of the company.

Use the following steps as a guide for initiating use of DfE. Once established, enhancements such as computer analysis programs can be added later.

- establish internal support
- build a team
- select and customize a DfE tool
- integrate into current design procedures

Step 1. Establish internal support

An important first step is to establish support for this opportunity to improve or enhance current design procedures by introducing other employees and management to DfE. Showing the *Better by Design* video at a meeting is a great way to start. This brief video outlines DfE basics—what, how, why and who—with testimonials from 3M, IBM, Medtronic, and General Mills. Follow-up discussions and meetings are essential to engage fellow employees and gain key management support. Inviting guest speakers from companies currently using DfE or some type of green design process can also be helpful.

Step 2: Build a team

Expanding a product design team to include a biologist and representatives from your environmental, health and safety department (EHS) can open new avenues for design. A biologist could contribute design ideas from a biomimicry perspective, tapping into the vast resources of natural design. EHS staff can contribute information related to regulatory or customer restrictions and hazardous waste management costs; the materials process group can suggest alternative materials.

Traditional members continue to be essential; representatives from the marketing, research and development (R&D), production, and engineering departments each contribute key information and considerations to the process.

Step 3: Select a tool or method

There are a number of methods or tools that provide a framework for design teams using of DfE. These range from a basic checklist or flow chart to supplemental software programs (see pages 14-23). Investing time and resources into selecting and customizing the right tool that reflects the values and the culture of a company is key. While there are various methods of implementing DfE, a core element is the entire team's use of a life-cycle perspective up front during product design. At the same time, each individual team member is encouraged to bring forward options and new ideas.

Step 4: Integrate DfE into design procedures

If written design procedures such as a guide manual are typically followed during product design, DfE checklist or flow chart pages can easily be added as tools for a team to use early in the process. Less-formal design processes can also use the same type of basic tools early on. It is important to customize checklists and flow charts to reflect the primary environmental concerns and culture of the company. For example, if the product is manufactured in a region particularly sensitive to water use, that aspect could be reflected in the checklist by assigning more points or weight to the "yes or no" questions about water use.

The method used is less important than providing an opportunity for a design team to take a life-cycle perspective, then leverage their aggregate ingenuity. It is also important to build ample time into the process for individual team members to research and present new, improved design attributes. Types of tools are described in the following section. *Continued on page 14.*

Materials Selection: Recycled & renewable parts

Raw materials for Mercedes Benz

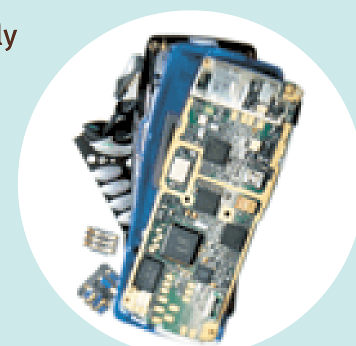
The new A-Class Mercedes Benz automobile has 26 components made from natural fibers such as flax, hemp, coconut, and sisal. For example, the covers for the front seat backrests are made of natural materials and plastic. The company sees the use of natural materials as an important contribution to reducing carbon dioxide emissions.

Abaca, a natural fiber grown in the Philippines, could even replace glass fiber as a strengthening agent for the car body plastic parts due to its exceptional tensile strength, lower weight, superior ease of use and suitability for recycling.

Overall materials selection is made on the basis of low consumption of resources, outstanding recycling properties, a minimal energy requirement, and low emissions during manufacture, processing, and use. A total of 54 components in this vehicle are made from high-quality recycled plastics.

www.germancarfans.com/news.cfm/newsid/2040915.008/mercedes/1.html

End of product life: Active disassembly



The Nokia Research Center has developed a prototype phone with a built-in "active disassembly" mechanism to aid in recycling materials at the end of the product's life. This mechanism stays dormant during the use phase of a product, but is activated when an external trigger such as heat is applied when it is time to disassemble the product. This enables more efficient and safe recycling of product.

For example, "shape memory" materials, such as a threaded screw or snap-fit connector, are molded and lose their shape when heat is applied (no threads on the screw, no curve on the snap-fit part) and then return to their original molded shape as they cool. When this type of connector is used in conjunction with strategically placed springs, a product such as this prototype cell phone self disassembles when heat is applied. The key is to design products so that it is unlikely they will be exposed to the external disassembly trigger (in this case, a specific amount of heat) during normal or even harsh use of the product. www.nokia.com

By disassembling electronic products instead of shredding them as a whole and then separating the materials, we can improve recovery rates of plastics, precious metals, and components that require special handling before recycling. Research continues in active disassembly through the European Union Fifth Framework program, Active Disassembly Using Smart Materials (ADSM). www.brunel.ac.uk/research/adsm/info/home.html

www.activedisassembly.com/index3.html

End of product life: Closed-loop solution

Baltix Furniture

Baltix (Long Lake, Minnesota) manufactures office furniture from natural materials, including wheat straw, sunflower husks, and recycled paper, currency, and plastics. No harmful adhesives, formaldehydes, or volatile organic compounds are used in the products. By accepting the office furniture back for reuse or recycling when it is no longer useful, Baltix provides a closed-loop solution that keeps old office furniture out of the waste stream.

Baltix products are designed "green from the ground up," using Leadership in Energy and Environmental Design Green Building Rating System® standards for commercial interiors.

Raw materials and manufacture

Wool and ramie are the natural fibers used in DesignTex fabric. The design team screened and selected every process and related ingredient used to produce the fabric. All the raw materials are put through "intelligence filters," where each potential dye or process chemical was analyzed so that any known or suspected carcinogen, mutagen, teratogen, bioaccumulative chemical, or endocrine disruptor are eliminated. "This complete screening of ingredients ensures that these fabrics are entirely safe, always." (*ClimatexLifecycle, The Ecology of Textiles*)

In addition, there is no waste stream from the mill that manufactures the fabric. Any by-products or trimmings are either reused in the manufacturing process or made into a compostable felt used by European gardeners to insulate crops. DesignTex fabric is designed to biodegrade and decompose naturally back into the soil and to nourish the earth, completing the life-cycle circle.

www.climatex.com

DesignTex fabric, typically used for office furniture, was designed by carefully considering the environmental impacts for the product's entire life cycle.This fabric was intentionally designed to have a circular, sustainable life cycle. The environmental impacts were carefully considered for each life-cycle stage.

Continued from page 13.

DfE tools

There are many methods or tools that can inspire design teams to develop innovative attributes in products—attributes that simultaneously benefit the consumer, manufacturer, and the environment. To insure long-term use, it is important to choose a design tool or method that is compatible with the processes and culture of your company.

There is no one "right way" to integrate DfE into product design. What is important is to have a system in place that motivates product design teams to improve design. DfE guides design teams through a life-cycle perspective with built-in windows of opportunity to optimize design. A checklist is a good tool to start with. Software tools or flow charts can then be added later. Either the use of stand-alone or any combination of tools could be the right choice for your company.

A description of each of the following types of DfE tools is included in this section:

- checklist
- flow charts
- Eco-Indicator 99
- software tools

Investment in selecting, then customizing a tool that will be integrated into the design process will generate payoffs for inspiring better design, generating cost savings, and potential gains in market share on a long-term basis.

Just the facts: Measuring impact

At best, it is difficult, if not impossible, in many instances to accurately measure the environmental impacts of a product over its entire life cycle. While an accurate measurement or life cycle analysis (LCA) has been done on some products, it is a very time-intensive, expensive process that can still generate disputable results. For example, where should the life-cycle boundaries be drawn for a raw material? Is it at obtaining the rubber for the tires on the truck that transports the mined metal that will be used in your product? How far back and to which sources of environmental impacts should the measurement go?

The checklist in this guide is based on an abridged or streamlined life-cycle approach with boundaries drawn around what a manufacturer can control. For example, materials selection is designated as the first life-cycle stage, since manufacturers generally control where they purchase parts and raw materials. Environmental impact information for this stage is obtained by surveying suppliers. If the suppliers are third tier, they can in turn survey their suppliers, and so on to cause a cascading effect. The result can be purchase of raw materials or parts with fully disclosed ingredients (no surprises) from a vendor that has good environmental practices.

There are tools based upon quantified measurement of impacts such as the Eco-Indicator 99 and some of the DfE software tools. Understand, however, when using these tools that the impact measurements are geographically based and primarily have an environmental, not public health, bias. For example, an eco-indicator for aluminum may be based on water impact information relative to a specific region of Europe. Also most of the emphasis on impact measurement tends to be relative to the environment and not worker exposure. These are good tools to use to provide guidance during decision making, keeping in mind that the results are not absolute. As with other tools, the quantified results are for internal comparison use only and would not, for example, be included on a product label as being absolute values.

The lack of entirely objective environmental impact data may be frustrating to some, however these tools are the best available at this stage of our understanding of environmental impacts. When using currently available DfE tools, there are subjective or value-laden decisions that need to be made based on your company's priorities and current information. The key is not to use tools for generating absolute measures, but for comparisons and to guide decision making, while inspiring design teams to draw upon their aggregate ingenuity and creativity.

Checklist questions

A checklist is a simple way to integrate DfE into design. Each section of this sample checklist has "open-ended" questions to start dialogues between design team members, as well as "yes or no" questions that address specific concerns. To give design teams new perspectives, this tool covers all of the life-cycle stages of the product upfront. At the same time, it opens windows of opportunity for considering design alternatives and use of innovative solutions.

Before using this sample checklist, customize it with questions relevant to the design of a particular product line and the culture of your company. For example, Baxter, a major medical products manufacturer, uses open-ended questions such as "Can we design it so that it could be upgraded and put back into the marketplace?" in their Product Sustainability Review (PSR). In addition, the answers can be "weighted" or assigned points that reflect the areas of most concern. Scores from the checklist are for internal, comparison use only.

Wind-up Laptop

Developed by scientists at One Laptop per Child (MIT's Media Lab) this inexpensive, wind-up computer was designed for children in the developing world. Where no electricity is available it can be powered by a hand crank. http://laptop.media.mit.edu/

Design Tip: Materials Selection

Some manufacturers such as S.C. Johnson and Seagate Technology, Inc. have developed lists of materials to avoid using in products, with the specific goal of eliminating or "designing out" the use of dozens of hazardous substances in the conceptual and preliminary design phases of new products and programs. The list has both prohibited and restricted materials that can only be used with review and special approval.

Substitutes for those materials on the restricted list can also be listed such as alternative flame retardants (see Appendix F: Alternative Flame Retardants).

Design Tip: Energy

Light-emitting diodes (LEDs) are increasingly being used in a variety of ways as a source of light for products. Characterized by their long lives of 10 years or more, LEDs are cool to the touch, very energy efficient, and operate at a fraction of the cost of other types of lighting. The Westinghouse LED Lighting Systems Marquee 60 bulb uses a single LED with a plastic ribbon to enhance the light effects. This light bulb can be is used in place of standard incandescent bulbs and yields savings of 90 percent for energy and up to 100 percent for maintenance with no noticeable heat transmission. www.w-led.com/marqueebulbs

I. Materials Selection

Obtain this information directly from your parts and raw materials suppliers. Typically companies mail surveys to suppliers to obtain this information prior to signing purchasing contracts to ensure raw material purity/quality.

Discussion questions

Are there plant or biobased materials or by-products from other processes that can be used as raw materials for this product?

Are there recyclable or compostable materials that can be used in this product?

1 POINT = YES, 0 POINTS = NO, UNLESS OTHERWISE NOTED

1. What percent of your company's suppliers for this product or component have an environmental management system (EMS) in place? (circle one)

0% or unknown	0 points
1 to 5%	2 points
6 to 25%	3 points
26 to 50%	4 points
→50%	5 points

2. What percent of your company's suppliers for this product or component have formal energy conservation practices in place, such as the Environmental Protection Agency's Green Lights Program? (circle one)

0% or unknown	0 points
1 to 5%	2 points
6 to 25%	3 points
26 to 50%	4 points
→50%	5 points

3. The parts or materials in this product do not contain any of these restricted use materials (or in an amount lower than what is allowed). See Appendix A: Restrictions in Use of Materials or develop a custom list with customers. (5 points for each material not in the part or material)

( ) Yes, describe briefly ____________________

( ) No

These EnLux bulbs are drop-in replacements for incandescent floodlights. These LED bulbs are "environmentatlly safe, 100% recyclable and last for years."

II. Manufacture

Discussion questions

Can this product be manufactured with low-temperature or low-energy use processes? (For example, low-temperature lamination process.)

Can this product be manufactured without the use of hazardous chemicals or restricted metals?

1 POINT = YES, 0 POINTS = NO, UNLESS OTHERWISE NOTED

1. Is the number of types, composite mixtures, and amounts of materials used in this product minimized?

( ) Yes, describe briefly ______________________

( ) No

2. Are the number and types of manufacturing steps minimized (simplification to prevent errors and waste)?

( ) Yes, describe briefly ______________________

( ) No

3. Does the product contain materials that are considered to have the least environmental impact?

( ) Yes, describe briefly ______________________

( ) No

4. Is as much recycled and/or renewable material as possible used in this product?

( ) Yes, describe briefly ______________________

( ) No

5. Is the amount of material used in the product and during the manufacturing process (surplus coating,cut-aways, trimming, by-products) minimized?

( ) Yes, describe briefly ______________________

( ) No

6. If plastics are used, are they clearly marked by an identification system such as ISO 1043-1 or ASTM D1972-91?

( ) Yes, describe briefly ______________________

( ) No

7. Do the manufacturing processes for this product minimize the use of energy-intensive steps (for example multiple heating and cooling, use of inefficient motors)?

( ) Yes, describe briefly ______________________

( ) No

8. Is there minimal transport between manufacturing and assembly points?

( ) Yes, describe briefly ______________________

( ) No

Design Tip: Optimizing Fasteners

There are a number of ways to optimize use of fasteners to facilitate upgrade, repair, and assembly/disassembly (for recycling) of products.

- consider color coding connectors to their corresponding point of attachment
- use snap-fit fasteners where possible
- if screws are used, use the same head type
- avoid use of glues or welds
- use a simple component orientation with visible fastening points
- consider using fasteners of the same material type as the parts to be joined to facilitate recycling

9. Is the consumption of water and generation of water pollutants avoided or minimized during the manufacture of this product?

( ) Yes, describe briefly ____________________

( ) No

10. Is the generation of air pollutants avoided or minimized during the manufacture of this product?

( ) Yes, describe briefly ____________________

( ) No

III. Product Use

Discussion questions

Could this product be made to use a renewable or alternative (such as a fuel cell) source of energy?

Could this product be designed for repair or upgrade by the consumer (e.g., use of modules or readily available replacement parts)?

1 POINT = YES, 0 POINTS = NO, UNLESS OTHERWISE NOTED

1. Is the product easily disassembled for repair, upgrade or reuse?

( ) Yes, describe briefly ____________________

( ) No

2. Are parts readily available for repair of this product?

( ) Yes, describe briefly ____________________

( ) No

3. Have potential barriers to recycling been avoided, such as use of fillers, additives, embedded metal threads in plastics, paint applied to plastics, or use of materials of unknown composition?

( ) Yes, describe briefly ____________________

( ) No

4. Does the design avoid disposable components such as "one-time use" cartridges, containers, or batteries?

( ) Yes, describe briefly ____________________

( ) No

5. If the product uses electric power, has energy efficiency been optimized?

( ) Yes, describe briefly ____________________

( ) No

6. Are all batteries in the product easily identifiable by type and removable?

( ) Yes, describe briefly ____________________

( ) No

7. Is the generation of water pollutants avoided or minimized during the use of this product?

( ) Yes, describe briefly ____________________

( ) No

8. Is the generation of air pollutants avoided or minimized during the use of this product?

( ) Yes, describe briefly ____________________

( ) No

- Electronic product manufacturers can use the ECMA checklist Annex A, which contains an extensive checklist for energy use (the stage for most environmental impact for electronic products), conservation during save, hard off, no load modes, at www.ecma-international.org/publications/standards/Ecma-341.htm

IV. Packaging and Transport

Discussion questions

Is there a creative way to reduce packaging while still meeting labeling and market demands (enhance the product's image)?

If the packaging container is reusable, can it be made to be easily collapsed or folded then reassembled?

1 POINT = YES, 0 POINTS = NO, UNLESS OTHERWISE NOTED

1. Has the amount of packaging materials for the product been minimized?

( ) Yes, describe briefly ____________________

( ) No

2. To aid in reuse or recycling, do packaging closures use paper tape and starch-based glues? (Avoid plastic tapes, plastic envelopes, and a lot of staples.)

( ) Yes, describe briefly ____________________

( ) No

3. If the packaging is paper, is it made with at least 30% post-consumer content or a non-wood alternative such as kenaf?

( ) Yes, describe briefly ____________________

( ) No

4. If the packaging is plastic, is it appropriately marked (according to ISO 11469)?

( ) Yes, describe briefly ____________________

( ) No

5. Do the packaging and ink printing meet the 100 ppm limit for combined concentrations of lead, cadmium, mercury, chromium-VI, including inks, adhesives, and coatings? (EU Directive 94/62/EEC and a number of U.S. states, www.packaginglaw.com/index_mf.cfm?id=153)

( ) Yes, describe briefly ____________________

( ) No

Design Tip: Packaging & Transport

Contamination of packaging materials can be minimized for recycling or reuse by following basic tips:

- Avoid the use of color and clear plastics in packaging; even if the polymer is the same, recycling of the material becomes limited.
- Inks, adhesives, coating, and labels often have to be removed prior to recycling; minimize or avoid using them.
- Interlocking tabs on paperboard packaging and press-studs on plastic packaging can eliminate the need for adhesives.
- Check with a local paper mill to find out which adhesives are best to use for recycling of paper products.
- Review product packaging waste restrictions (Appendix A: Restrictions in Use of Materials).
- Use water- or starch-based coatings on paperboard (instead of wax or polyethylene).

To reduce waste, reusable transport packaging such as collapsible, returnable totes can be used, especially when transporting parts and supplies for products between plants or facilities. For more information on reusable transport packaging: www.moea.state.mn.us/transport/index.cfm

6. If paperboard and/or paper is used for packaging, is it unbleached or made from a totally chlorine free (TCF) or elemental chlorine free (ECF) bleaching process?

( ) Yes, describe briefly ______

( ) No

7. If adhesives and inks are used are they water based and/or soy (plant based) instead of solvent based?

( ) Yes, describe briefly ______

( ) No

8. Can the shape of the package be altered to improve case/palletization/ transport efficiency?

( ) Yes, describe briefly ______

( ) No

9. Is the lightest weight of packaging material used?

( ) Yes, describe briefly ______

( ) No

V. End of Product Life

Discussion questions

Are there new types of fasteners or joining technology that could be used to make this product easier to disassemble?

Can the product be designed with residual value in mind, so that it or its parts have monetary value at the end of usefulness (an incentive to reuse, recycle, or compost the product or parts)?

1 POINT = YES, 0 POINTS = NO, UNLESS OTHERWISE NOTED

1. Is the product easily disassembled for reuse, recycling, or composting at the end of product life?

(1 point = yes, 0 points = no)

( ) Yes, describe briefly ______

( ) No

2. Are the materials used in the product easy to identify by type and to separate?

( ) Yes, describe briefly ______

( ) No

Design Tip: Disassembly

Designing a product for ease of repair or disassembly can include a number of options:

- use modules (self-contained units or assemblies) that are easily removed
- make fasteners from the same material as the components
- minimize the number and length of connecting wires and cables; use direct “docking” or connection of printed wire boards when possible

See the Innovative Fasteners Guide Sheet for more information.

3. Are any of the materials used in the product required to be disposed of as hazardous waste (in U.S. or other countries where product may be sold)?

( ) Yes, describe briefly ____________________

( ) No

4. Has the intentional introduction of "restricted use" materials (as listed in Appendix A, page 24) been avoided?

( ) Yes, describe briefly ____________________

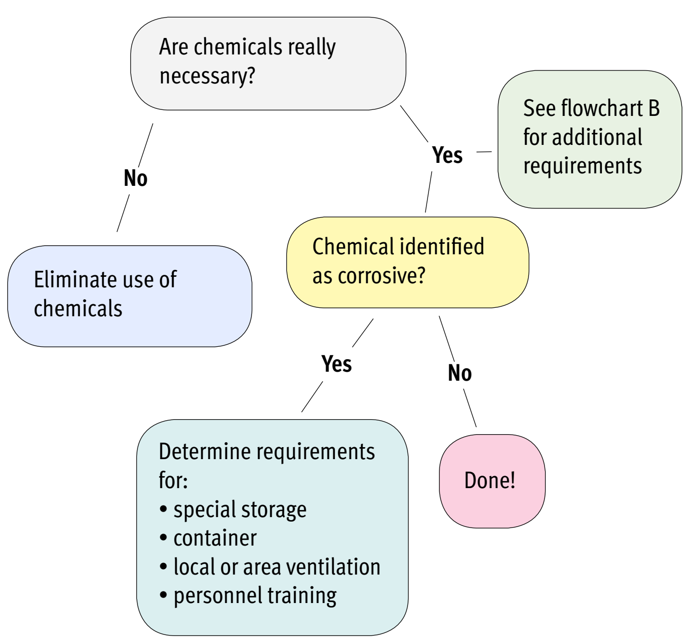
( ) No

Total

Flow charts

Flow charts offer a visual, decisive method for guiding and analyzing a product's design features. By using flow charts, a product design team can easily progress through key decision-making points. For example, in one of the flow charts in Medtronic's "Environmental Product Evaluation Plan," the first question is: "Are chemicals really necessary?" If a product and related manufacturing process does not require chemicals, the evaluation is complete. If chemicals are needed, the design team must complete this flow chart, then fill out justification paperwork. The result is a built-in incentive to minimize the use of chemicals in the design of products, since fewer chemicals means less paperwork and justification. This can prevent the accrual of costs, due to unnecessary use and disposal of chemicals over many years.

Depending upon how they are constructed, flow charts can be used as a stand-alone tool or as part of an array of tools that initiate use of DfE in a way that is compatible with the practices and culture of a company.



A partial view of a flowchart used by Medtronic, Inc. to implement design for the environment.

Eco-Indicator 99

Eco-indicator 99 is a method of evaluating the impacts (human health, ecosystem, and resources) of various materials and processes. It was developed by PRe Consultants for the Dutch government. A Complete Eco-indicator 99 Manual for Designers is at http://www.pre.nl/download/EI99_Manual.pdf.

When using this tool, keep in mind that the impact measurements are geographically based (derived from impacts on a particular region) and primarily have an environmental, not public health bias. Also most of the emphasis on impact measurement tends to be relative to the environment and not worker exposure. These are good tools to provide guidance during decision making, but keep in mind that the results are not precise, undisputable values. As with other tools, the quantified results are for internal, comparison use only and would not, for example, be included on a product label as being absolute values.

Below is a section from the tool, which displays the eco-indicator values. The methodology described in the downloadable manual needs to be followed when using this tool.

Processing of metals (in millipoints)

	Indicator	Description
Bending – aluminium	0.000047	one sheet of 1mm over width of 1 metre; bending 900 4
Bending – steel	0.00008	one sheet of 1mm over width of 1 metre; bending 900 4
Bending – RVS	0.00011	one sheet of 1mm over width of 1 metre; bending 900 4
Brazing	4000	per kg brazing, including brazing material (45% silver, 27% copper, 25% tin) 1
Cold roll into sheet	18	per thickness reduction of 1 mm of 1 m2 plate 4
Electrolytic Chromium plating	1100	per m2, 1 μm thick, double sided; data fairly unreliable 4
Electrolytic galvanising	130	per m2, 2.5 μm thick, double sided; data fairly unreliable 4
Extrusion – aluminium	72	per kg 4
Milling, turning, drilling	800	per dm3 removed material, without production of lost material 4
Pressing	23	per kg deformed metal. Do not include non-deformed parts! 4
Spot welding – aluminium	2.7	per weld of 7 mm diameter, sheet thickness 2 mm 4
Shearing/stamping –aluminium	0.000036	per mm2 cutting surface 4
Shearing/stamping – steel	0.00006	per mm2 cutting surface 4
Shearing/stamping – RVS	0.000086	per mm2 cutting surface 4
Sheet production	30	per kg production of sheet out of block material 4
Band zinc coating	4300	(Sendzimir zink coating) per m2, 20-45 μm thick, including zinc 1
Hot galvanising	3300	per m2, 100 μm thick, including zinc 1
Zinc coating (conversion um)	49	per m2, 1 extra μm thickness, including zinc 1

Production of non ferro metals (in millipoints per kg)

	Indicator	Description
Aluminium 100% Rec.	60	Block containing only secondary material 1
Aluminium 0% Rec.	780	Block containing only primary material 1
Chromium	970	Block, containing only primary material 1
Copper	1400	Block, containing only primary material 1
Lead	640	Block, containing 50% secondary lead 1
Nickel enriched	5200	Block, containing only primary material 1
Palladium enriched	4600000	Block, containing only primary material 1
Platinum	7000000	Block, containing only primary material 1
Rhodium enriched	12000000	Block, containing only primary material 1
Zinc	3200	Block, containing only primary material (plating quality) 1

Software tools

There are a variety of software tools that are useful for guiding decision making by product design teams. Some of these tools have a materials selection emphasis, providing comparative graphs and charts to assist with determining which material may be best to use. They can be used in conjunction with a checklist that covers the rest of the life-cycle stages. These tools are especially useful for providing comparative data for team members who want more measurement. While these tools often involve a financial investment, demonstration models may be available on a trial basis by contacting the vendor.

Software Tools Useful for DfE	
SimaPro	www.pre.nl/simapro/default.htm
Boustead	www.boustead-consulting.co.uk
Umberto	www.pre.nl/umberto/default.htm
Gabi	www.gabi-software.com
Eco IT	www.pre.nl/eco-it/eco-it.htm
Idemat	www.io.tudelft.nl/research/dfs/idemat/Onl_db/od_frame.htm
Ecoscan	www.ind.tno.nl/en/product/ecoscan/
P2 Edge	http://availabletechnologies.pnl.gov/infotechenergy/pol.stm
Eco-indicator 99	www.pre.nl/eco-indicator99/default.htm
DFE	www.ind.tno.nl/product_development/sustainable_concepts/dfe/download.html
MERGE ™	www.environmentaldefense.org/alliance/merge/Merge.htm

Appendix A: Restrictions in Use of Materials

There are a number of restrictions in the use of certain materials or chemicals in products by a number of countries. Some of these restrictions relate to specific types of products; for example, the European Union Restrictions on the use of Hazardous Substances (RoHS) list of materials applies to most electronic products sold in Europe. For information on specific allowable levels or concentrations of each material refer, to the language in each regulation. Copies of the entire EU legislative documents are at EUR-Lex: http://europa.eu.int/eur-lex/. Electronics manufacturers can contact the Electronic Industries Alliance (EIA) to obtain a "Material Composition Declaration for Electronic Products."

Material	Directives & Regulations
Asbestos	EU 76/769/EEC Council Directive on restrictions on the marketing and use of certain dangerous substances and preparations.
Ozone Depleting Substances: chlorofluorocarbons (CFC), hydrobromofluorocarbons (HBFC), hydrochlorofluorcarbons (HCFC), Halons, carbontetrachloride, 1,1,1-trichloroethane, bromochloromethane	EU: Regulation (EC) No. 2037/2000 on substances that can deplete the ozone, 2038/2000, 2039/2000
Polychlorinated biphenyl (PCB), polychlorinated terphenyl (PCT), monomethyltetrachlorodiphenylmethane (brand name Ugilec 141, 121, or C21), monomethyldibromodiphenylmethane (DBBT)	EU 76/769/EEC Council Directive on restrictions on the marketing and use of certain dangerous substances and preparations.
Mercury	2002/95/EC Restrictions on the Use of Hazardous Substances (RoHS) Netherlands decree on Product Containing Mercury, 1998 Environmentally Hazardous Substances Act
Polychlorinated naphthalene (PCN), Triphenyl Tin (TPT), Tributyl Tin (TBT), Tributyl Tin Oxide (TBTO)	Japanese Law No. 117 of Oct. 16, Year-Showa-48 (1973) - Chemical Substance Control Law
Di-U-Oxo-di-n-butyl-stanniohydroxyborane (DBB)	EU 76/769/EEC Council Directive on restrictions on the marketing and use of certain dangerous substances and preparations.
Pentabromodiphenyl ether (PentaBDE, OctaBDE)	EU 76/769/EEC Council Directive on restrictions on the marketing and use of certain dangerous substances and preparations. 2003/11/EC Restrictions on the marketing and use of certain dangerous substances and preparations (pentabromodiphenyl ether, octabromodiphenyl ether)
Lead, cadmium, mercury, hexavalent chromium, PBB, PBDE	From July 2006 on: EU Directive 2002/95/EC (RoHS) - lead, cadmium, hexavalent chromium, and mercury are also banned from intentional introduction or levels exceeding 100 parts per million in ink, dye, pigment, paint, or fungicide products for sale in Minnesota, Minn. Statute 115A.9651. Bans on penta and octa PBDE California (AB302), Hawaii (HB2013), and Maine (LD1790)
Plastic Parts	
Cadmium or cadmium compounds in plastic parts	EU 76/769/ECC amendment 91/338/EEC
Short chain chloroparaffins	Dutch decree 478 3.11.1999, Norwegian regulation relating to restrictions on the use of certain dangerous chemicals 20.12.2002
Lead or lead compounds in plastic parts	Dutch Statutory Order No. 1012 of 13 November 2000 on Prohibition of Import and Marketing of Products Containing Lead
Polyvinyl Chloride in Toys	Eight EU Member States have adopted national bans since 1998 (Austria, Greece, France, Italy, Finland, Denmark, Sweden, Germany).
Benzeneand phthalates in Toys	EU 76/769/EEC Council Directive on restrictions on the marketing and use of certain dangerous substances and preparations.
Pigments, Paints & Coatings	
Cadmium or cadmium compounds in paints, coatings or pigments	EU 76/769/EEC Council Directive on restrictions on the marketing and use of certain dangerous substances and preparations.
Lead or lead compounds in paints, coatings, or pigments	Danish Statutory Order No. 1012 of 13
Textiles and Leather	
Tri-(2,3,-dibromopropyl)-phosphate (TRIS) Tris-(aziridinyl)-phosphineoxide (TEPA)	EU 76/769/EEC Council Directive on restrictions on the marketing and use of certain dangerous substances and preparations.
Azo dyes that split aromatic amines	EU 76/769/EEC Council Directive on restrictions on the marketing and use of certain dangerous substances and preparations. (2003/3/EC) Restrictions on the marketing and use of "blue colourant"
Hexavalent chromium	German Food and Commodities Law (LMBG)
Nickel	For articles coming into direct and prolonged contact with skin. EU 76/769/EEC Council Directive on restrictions on the marketing and use of certain dangerous substances and preparations.
Wood Preservatives	
Arsenic	EU 76/769/EEC Council Directive on restrictions on the marketing and use of certain dangerous substances and preparations. (2003/2/EC) Amendment on restrictions in marketing and use of arsenic (10th adaptation to technical progress)
Mercury	EU 76/769/EEC Council Directive on restrictions on the marketing and use of certain dangerous substances and preparations.
Pentachlorophenol and derivatives	EU 76/769/EEC Council Directive on restrictions on the marketing and use of certain dangerous substances and preparations.
Product Packaging	
Sum concentrations of lead, cadmium, mercury, chromium-VI does not exceed 100 ppm by weight	EU Directive 94/62/EEC Packaging and packaging waste (intentional introduction of these materials into packaging or related inks, dyes, pigments, adhesives, stabilizers is also banned in California, Connecticut, Florida, Georgia, Illinois, Iowa, Maine, Maryland, Minnesota, Missouri, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, Virginia, Washington, and Wisconsin).

Adapted with permission from Ecma International www.ecma-international.org.

Appendix B: ISO Plastics Identification System

The International Organization for Standardization (ISO) of Geneva, Switzerland, has developed a comprehensive standard for marking plastics. An example of an ISO product marking for a blend of plastics would be >ABS + PC< for an acrylonitrile/butadiene/styrene + polycarbonate blend. Polybutylene terephthalate with 15% glass fiber + 25% mineral reinforced would be marked as >PBT-(GF15 + M25)< on the product. The markings should be easily found, at least 3 mm high, in all capital letters, and designed to last the life of the product. To purchase the entire ISO 1043-1 standard for marking plastics go to http://webstore.ansi.org/ansidocstore/iso.asp.

ISO 1043-1 Plastics Identification System

Symbol	Plastic Polymer Chemical Name
ABS	Acrylonitrile/butadiene/styrene
ABS-FR	Flame-retardant ABS
EP	Epoxy
PA	Nylon (polyamide)
PA6	Nylon 6
PA66	Nylon 6/6
PBT	Polybutylene terephthalate
PC	Polycarbonate
PE	Polyethylene
PE-LLD	Linear low-density polyethylene
PE-LMD	Low-medium density polyethylene
PE-HD	High-density polyethylene
PET	Polyethylene terephthalate
PS	Polystyrene
PS-HI	High-impact polystyrene
PCV	Polyvinyl chloride
SAN	Styrene/acrylonitrile
SI	Silicone
Symbol	Filler Name
GF	Glass fiber
GB	Glass bead
MP	Mineral powder
CF	Carbon fiber

Appendix C: International Ecolabel Programs

Meeting the requirements of an ecolabel is a good way to gain endorsement and to preemptively meet regulatory requirements for products. In addition to the ecolabel programs included in this chart, there are also ISO 14021 and ISO 14025 self-declaration labels (www.scscertified.com).

Ecolabel	Logo	Web site	Affiliated country
Australian Ecolabel		www.aela.org.au	Australia
Blue Angel		www.blauer-engel.de	Germany
Eco Mark		www.jeas.or.jp	Japan
China Environmental Logo		http://en.beijing-2008.org/09/29/article211622909.shtml	China
Energy Star		www.energystar.gov	USA, Canada, Australia, EU countries, Japan, Taiwan
Environmental Choice Programme		www.environmentalchoice.com	Canada
Nordic Swan		www.svanen.nu	Denmark, Norway, Sweden
TCO Development		www.tcodevelopment.com	Sweden
EU Eco-label Scheme		http://europa.eu.int	European Union Countries
Green Label Scheme		www.greencouncil.org	Hong Kong
Green Label Programme		www.tei.or.th	Thailand
C2C Certification		www.c2ccertified.com	United States
Waste Electrical and Electronic Equipment (WEEE)		www.dti.gov.uk/sustainability/weee/	European Union Countries

Appendix D: Bio-materials Resources

Bio-Materials	Description	Website
TREEPLAST@	Made from crushed corn, wood chips, and natural resins is fully biodegradable.	www.treeplast.com
ARBOFORM@	Made from 100% renewable raw materials and is mainly used for injection molded wood applications.	www.arboform.org
SLP, Starch Bound Low Density Wood Product	Produced from sawdust and wood flour is an organic product made without harmful additives, contains no glue (and therefore no formaldehyde)	www.iwood.ch/PROD_1_0_0_e.html
Duralmond	Made from ground almond shells and resins.	www.rapsel.de/technik/material.html

More information on biomaterials can be found at the Journal of Polymers and the Environment at jepd.caeds.eng.uml.edu

Biodegradable plastic

- Current listing of biodegradable plastics by generic and trade name (producer) published by the Biodegradable Plastics Society: www.bpsweb.net/02_english/03_new_e/what_g/what.htm (scroll to bottom of page)
- Current list of products made from biodegradable polymers are at www.bpsweb.net/02_english/03_new_e/mark_syouhin/mark_shouhin.htm

www.biopolymer.net

Ecofriendly packaging materials are at www.friendlypackaging.org.uk/novel.htm#novel

Appendix E: Green Fabrics

Brand Name	Material Used	Contact Information for Swatches
Luna Textiles	100% recycled polyester	(415) 252-7125
EcoSpun	100% recycled polyester	www.eartheasy.com/wear_ecospun.htm
Climatex	wool and ramie	www.climatex.com
Terratex	100% recycled polyester	www.terratex.com or (800) 544-0200
Nature Works - Ingeo Fiber	Biodegradable product made from polylactic acid (corn)	www.cargilldow.com/ingeo
Victor Innovatex	Antimony-free polyester, free of chlorine and persistent bioaccumulative toxins (PBTs), “perpetually” recyclable, produced with renewable energy.	www.victor-innovatex.com

Other “green” fabrics are listed at www.greensage.com/12050-fabric.html.
Information about the Unified Sustainable Textile Standard© 2.0 is at http://mts.sustainableproducts.com.

Appendix F: Alternative Flame Retardants

Halogen-free Flame Retardant	Polymer Types
Metal oxides	
Aluminum trioxide	Epoxy, ABS, HIPS, PC, EVA, XLPE
Magnesium hydroxide	Epoxy, ABS, HIPS, PC, nylons, PVC, EVA, XLPE
Magnesium carbonate	ABS, HIPS, PC, PVC, EVA, XLPE
Zinc compounds	
Zinc borate	Epoxy, nylons, PVC, EVA
Zinc hydroxystannate	PVC, EVA
Zinc stannate	Epoxy, nylons, PVC
Phosphorus-based compounds	
Red phosphorus	Epoxy, phenolic, nylons
Ammonium polyphosphate	Epoxy
Phosphate esters	Phenolic, ABS, HIPS, PC, PVC, EVA
Other	
Melamine derivatives	ABS, HIPS, PC, nylons

The rising levels of polybrominated diphenyl ether (PBDE), a halogenated flame retardant, in human fat tissues is the subject of a number of research studies. Because halogenated flame retardants may be persistent, bioaccumulative, and toxic, a number of manufacturers are seeking alternatives. Additional information about alternative flame retardants is at www.turi.org/content/content/view/full/2148/

Appendix G: ISO 14001 + DfE

International Organizations for Standards (ISO): Copies of standards

ISO is a network of the national standards institutes of 146 countries with a Central Secretariat in Geneva, Switzerland, that coordinates the system. The voluntary standards this organization publishes provide a framework for compatible technology worldwide to facilitate manufacturing, trade, and customer satisfaction. Some of these standards are also relevant for support of DfE in product design. While the ISO 14040 standard provides direct support for life-cycle concepts and design, other standards are also relevant to design.

Identify plastic polymers

The ISO 11469 standard specifies a system for uniform marking of plastic parts that provides complete information about the polymer used. For example >PC+ABS< is a blended polymer that is predominately polycarbonate and >PVC-P(DBP)< is a polyvinylchloride polymer that contains the plasticizer dibutyl phthalate. Use of ISO codes and symbols to mark polymers insures proper identification to aid in the recycling of these materials.

Survey suppliers

Use of an environmental management system (EMS) such as ISO14001 can reveal a lot about a company. It confirms that they have a system in place to address environmental concerns and that it is a primary area of focus. Some manufacturers require their suppliers to have an EMS in place as evidence of their continuous commitment to the environment. A common question on supplier surveys is, "Do you have an EMS in place?" It can provide certain amount of assurance to manufacturers; for example, a supplier with an EMS could be less likely to have unidentified ingredients or contamination of a pigment with cadmium or mercury. This affects not only future liability concerns, but product content declaration, and the overall quality of product design.

DfE as part of an ISO 14001 system

Manufacturers can include DfE as part of their ISO 14001 system from the start or add it later as part of continual improvement. This is an emerging trend; product design becomes an integral part of a comprehensive, systematic approach to addressing environmental concerns.

For more information on ISO standards: www.iso.org/iso/en/aboutiso/introduction/index.html#one.

To purchase copies, go to http://www.iso.org/iso/en/iso9000-14000/publications/iso9000_14000publications.html or for a catalog that lists all the ISO standards to http://webstore.ansi.org/ansidocstore/product.asp?sku=ISO+Catalog

Sources of Additional Information

Use these resources to find more in-depth information on key areas of emphasis or related topics.

- **Envirowise** has a number of online publications on cleaner production and DfE. www.envirowise.gov.uk/envirowisev3.nsf/key/mroz5yhg6m
- **Environmental Management Systems,** as defined by EPA, provide a framework for managing environmental responsibilities in a more systematic way, enabling organizations to continuously improve their environmental performance. www.epa.gov/region02/ems/
- **European Directive 2005/32/EC** (effective August 11, 2005) requires the use of ecodesign for energy-using products (EuP), including water-heating equipment, household appliances, office and HVAC equipment, and more, for companies producing 200,000 units or more/year. http://europa.eu.int/comm/enterprise/eco_design/directive_2005_32.pdf
- **Fibonacci Series** is formed by starting with 0 and 1 and then adding the previous two numbers to get the next (0, 1, 1, 2, 3, 5, 8, 13, ...). A Nautilus shell spiral is based upon a series of Fibonacci squares; each new square having sides as long as the sum of the previous two squares' lengths. The spiral shape of the shell fits within the boundaries of this progressive series of squares.
  - www.mcs.surrey.ac.uk/Personal/R.Knott/Fibonacci/fibseries.html
  - www.mcs.surrey.ac.uk/Personal/R.Knott/Fibonacci/fibnat.html
- **Green Chemistry**, or environmentally benign chemistry, focuses on the reduction or elimination of the use and generation of hazardous substances www.chemistry.org/portal/a/c/s/1/acsdisplay.html?DOC=education%5Cgreenchem%5Ccases.html
- **ISO/TR 14062** (2002) outlines the basic principles for considering the environment as a factor in product design. www.environmental-expert.com/magazine/ecomed/ehs/ehs2.pdf
- **Japan's appliance recycling and design laws**, Japan's Law for the Promotion of the Effective Utilization of Resources (LPEUR, June 2000), makes sustainable product design obligatory for household appliances, computers, photocopiers, mobile phones, and other electronic consumer goods. The Japanese Home Appliance Recycling Law (HARL, April 2001) stipulates minimal recycling rates for air conditioners, televisions, refrigerators, and washing machines. www.meti.go.jp/english/information/data/cReHAppre.html
- **Packaging design** "Packaging design for the environment: reducing costs and quantities" www.envirowise.gov.uk
  - www.envirowise.gov.uk/envirowisev3.nsf/key/packagingpublications
  - www.indes.net/eco-ref
- **Packaging guidelines**, a comprehensive textbook and reference written for the electronics industry, has universal green packaging design information. http://fiesta.bren.ucsb.edu/~green-pkg/EPG.pdf
- **Packaging – current regulations**: related to environmental requirements for electronic products are at www.eia.track.com. A number of countries require packaging reduction plans, have empty space requirements, minimum levels of recycled content, and restrictions on the types of materials that can be used.

- **Product examples**: products with environmental attributes. www.lboro.ac.uk/research/susdesign/InfoInsp/Inspiration/Home/Inspiration.htm
- **REACH Legislation**: In 2007, the European Union is expected to implement Registration, Evaluation and Authorization of Chemicals (REACH) legislation. The registration of chemicals is expected to include all substances produced or imported into the European Union in volumes of 1 ton and more per year per manufacturer or importer. Chemical manufacturers and importers distributing in the European Union will be required to provide information on the intrinsic properties, hazards, risk assessment, and risk reduction for each substance (such as physicochemical, toxicological, and eco toxicological properties). http://europa.eu.int/comm/environment/chemicals/reach.htm
- **Recycled Wood Guide for Furniture**: http://www.wrap.org.uk/publications/CompleteFurn.pdf
- **Reusable transport packaging**: Information about reusable transport packaging for businesses: www.moea.state.mn.us/transport/index.cfm
- **Sustainable furniture materials**: www.valuecreatedreview.com/greenoptions.htm
- **World Business Council for Sustainable Development** is a coalition of 175 international companies "united by a shared commitment to sustainable development via the three pillars of economic growth, ecological balance, and social progress." www.wbcsd.ch
- **WEEE (Waste Electrical and Electronic Equipment)** and **RoHS (Restriction of the Use of Hazardous Substances) Directives** from the European Union identify specific requirements for electronic products. Key features of the WEEE Directive include compulsory separation of WEEE from the municipal waste stream, marking the packaging with and producers funding the recycling/processing costs for this waste (in 2006). The RoHS Directive requires that new electronic equipment products do not contain more than maximum-permitted levels of lead, mercury, cadmium, and polybrominated biphenyls (PBBs) and polybrominated diphenylethers (PBDEs) (July 2006). www.envirowise.gov.uk/envirowisev3.nsf/key/CROD5PRJ23; www.envirowise.gov.k/envirowisev3.nsf/key/GG427

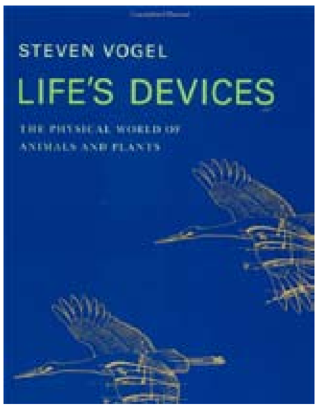
Natural patterns resources

Natural patterns

Patterns are a basic organizing principle of life. The cell is a pattern, boundaries are patterns, information transmission via DNA (or speech) consists of patterns. There are design patterns, process patterns, and patterns of exploration. The study of patterns can be a rich source for our design process. Biomimicry can be characterized as the study of natural systems patterns with applications to design. The study of biomimicry can be aided by knowledge of patterns.

The DfE perspective enables us to see our designs with fresh eyes. By using DfE, we tie our designs into more comprehensive patterns of energy and material. Here are some starting points for the study of patterns.

- *The Timeless Way of Building* by Alexander (ISBN 0195024028). In this book, the author discusses the "quality without a name" that infuses designs when they are alive. Beyond his marvelous philosophical point of view, the author gives practical procedures for creating and sharing patterns.



Life's Devices: the Physical World of Animals and Plants by Steven Vogel (ISBN 0-691-02418-9). A book that explores comparative biomechanics. "The physics and mathematics relevant to the world of organisms are rich in phenomena and interrelationships that are far more self-evident, and the materials themselves are complex and diverse."

- *Imitation of Life* by Forbes (ISBN 0262062410). This book focuses on metaphors from biology for computer design. Her overview of how current research on natural systems ties into design is valuable to others as well.
- *Way of the Cell* by Harold (ISBN 0195163389). For product designers, there may be no more fundamental component to study than the cell. It processes information and energy, keeps invaders out, and allows useful things in.
- *The Self-Made Tapestry* by Ball (ISBN 0198502443). A comprehensive look at how patterns form in a variety of natural systems. A rich source book for inspiration.

Applied biomimicry

Biomimicry requires knowledge of biology, and there is no substitute for a biologist on your team. You can find partners at your local university, and both sides will benefit. In the meanwhile, you'll find it useful look at examples of what others have done.

- *Wild Solutions* by Beattie and Ehrlich (ISBN 0300105061). A brief sampling of some natural systems that have served as metaphors for designed systems. This book can be read by a high school student.
- *Introduction to Bioengineering* by Fung (ISBN 9810243987). Intended for an introductory college course, this book is a collection of papers where the authors researched biological systems for applications in the biomedical field.
- *Shape and Structure*, From Engineering to Nature by Bejan (ISBN 0521793882). A fascinating look at how structures in nature can be models for engineering designs. Includes material on thermal structures and flow as well as mechanical structure.
- *Signs of Life: How Complexity Pervades Biology* by Sole and Goodwin (ISBN 0465019277). How do living systems follow simple rules yet create such exquisite order? The authors do the best job so far in exploring this territory.
- *Seeing Nature: Deliberate Encounters With the Natural World* by Krafel (ISBN 189013242x). Books and papers are all very good, but eventually we need to see the world with our own eyes and find patterns around us. This book will enable you to do that.

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PAX Scientific, *Capturing the Force of Nature*, www.paxscientific.com

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www.pca.state.mn.us