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Chemicals, Materials, and Waste

As *Cradle to Cradle* makes clear, everything that goes into a product eventually comes back in some form. And it's up to us, as engineers, to find more creative and eco-responsible ways to deal with it. Thinking of this from a lifecycle perspective, we need to consider the following.

- **The impact of sourcing specific materials:** Are the materials we're using dangerous to create? Are emissions related to their manufacture? Can we use recycled materials?
- **The safety aspects of products in use:** Does the product contain dangerous chemicals? Is there any potential for hazardous emissions?
- **The impact of materials at end-of-use:** Can the materials easily be taken apart and recycled? Are there any hazardous chemicals that will have to be reclaimed with special means (e.g., mercury in chlorofluorocarbons or CFLs)?

This chapter covers the regulations that impact the selection of materials, packaging and documentation considerations, and waste and renewal issues that impact product design such as disassembly, reusability, recycling, and take-back.

Chemistry and the Law

All of the potential dangers of chemicals and materials are not lost on the world's governing bodies. For example, the European Union's Reduction of

Hazardous Substances (EU RoHS) Directive already bans new electrical and electronic equipment from the EU market if it contains excessive levels of lead, cadmium, mercury, hexavalent chromium, polybrominated biphenyl (PBB), and polybrominated diphenyl ether (PBDE) flame retardants. But the RoHS Directive, passed in 2003, is only the tip of the iceberg.

Industrialized countries throughout North America, Europe, and Asia are now considering, drawing up, or in the process of implementing additional restrictions on the use of chemicals and materials. Current examples include the REACH (Registration, Evaluation, Authorization, and Restriction on Chemicals) regulations, dozens of new U.S. and EU battery laws, and a Chinese version of the RoHS Directive, among others. And multiple standards bodies worldwide are busy defining new requirements and standards for material declarations, based on Joint Industry Guide specifications, IPC data, IEC Working Group recommendations, and so on. It is important to note that these regulations not only include bans or limits on certain chemicals, but also involve reporting the usage of certain chemicals, or specialized handling of the chemicals at end-of-use of the product. Given the disparity of laws across different regulatory regions, these reporting and disposal regulations can become quite expensive to comply with.

Figure 8–1 provides a graphic example of how recent regulations have limited choices for engineers. When you eliminate from consideration the elements that are now banned for use in electronics by RoHS or other laws, the elements that may soon be banned through proposed legislation, and the elements that are useless in electronics, only about one-third of the periodic table remains available to engineers.

In addition, the WEEE Directive, made effective in July 2006, makes manufacturers responsible for e-waste, based on recovery, recycling, and collection targets. The legislation is designed with two aims in mind: to create an economic incentive for manufacturers to design more environmentally friendly products, and to reduce the environmental impact of waste by increasing the volume that is recovered and recycled.

To deal with this complexity, many companies are formalizing their product content restrictions through specification documents. Hewlett-Packard, for example, makes detailed specifications available to its supply chain covering product content and testing requirements for lithium and lithium-ion cells, batteries, and battery packs, as well as standards for the marking of plastic parts and products for subsequent decision making during the regeneration phase. If you work in a larger company, it's important to understand your company's standard approach to chemical decisions.

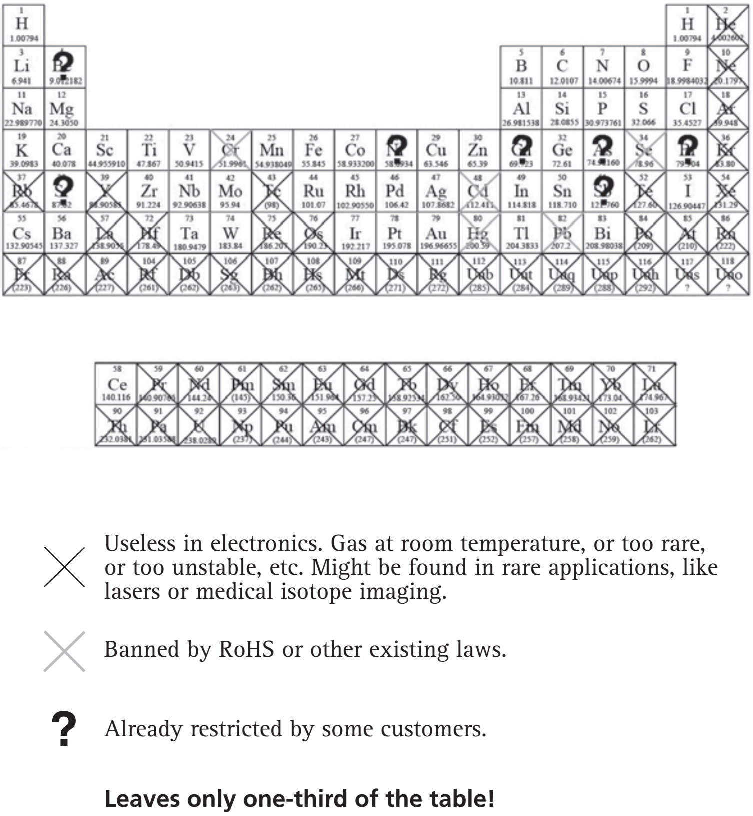

FIGURE 8–1 Elements of the Periodic Table That Are Not Suitable for Manufacturing, Are Banned, or Are Restricted

For more detailed information about current regulations relating to materials and chemicals, see the following URLs:

- WEEE regulations: www.dti.gov.uk/innovation/sustainability/weee/page30269.html
- RoHS Directive: www.rohs.gov.uk/
- U.S. General Environmental, Health, and Safety (EHS) Guidelines, April 30, 2007: www.ifc.org/ifcext/enviro.nsf/Content/EnvironmentalGuidelines
- iNEMI standards: www.inemi.org/cms/

In addition, industry trade groups and consultants can often help you understand the legal implications and alternatives for materials decisions.

Packaging and Documentation

Take a look at any consumer product on a store shelf and you'll see why packaging is a growing concern for environmentalists. A simple electric razor, for example, is sold encased in a clear, rigid, molded plastic container (usually unopenable and virtually indestructible!) that houses a variety of separately packaged components: a cardboard box containing the razor blades, a power cord in a shrink-wrapped plastic tube; plastic-wrapped batteries; and another shrink-wrapped packet with various instructions and warranty cards.

Or consider a poorly packaged personal computer, which ships in a box of boxes—with a separate package for each component (even the power cord)—layered with molded polystyrene and cushioned by Styrofoam or hundreds of Styrofoam peanuts. And depending on who buys the product, these packaging materials may be headed straight for the landfill right after the goods are unpacked.

Two points here: First, packaging is often almost pure waste. As engineers, we need to stop asking ourselves how to make packaging more efficient and start asking how to get away with less of it. The good side of this is that, just as we have seen in other areas, there is the potential for some significant savings if we can figure out how to package products more effectively and efficiently.

Second, the "product" and the "packaging" have their own separate lifecycles and supply chains, and engineers who are designing for optimal environmental effectiveness need to consider both of them. Why? Regulations covering design and take-back of packaging materials are mushrooming throughout Europe, Asia, and North America, and compliance with these environmental packaging laws requires creative engineering.

Policies related to packaging began to spread rapidly after the EU Directive on Packaging and Packaging Waste was published in 1994. This measure spawned similar policies in Eastern Europe and eventually Asia, and today environmental packaging requirements apply to products sold in most global markets, including[1]

- The Americas (United States, Canada, Brazil, Mexico)
- Europe (EU member states, Norway, Iceland, Switzerland, Bulgaria, Croatia, Romania, Turkey, Ukraine)

- The Asia/Pacific region (Australia, China, Japan, Taiwan, South Korea, India, Bangladesh)
- Africa/the Middle East (Tunisia, South Africa, Israel)

The specific regulations for any given product tend to be in a perpetual state of flux. The challenge for engineers is to develop a packaging solution that will be marketable in as many regions as possible, while keeping the cost and complexity of compliance at a minimum. This requires a thorough understanding of the requirements in each jurisdiction.

For example, in the EU all packaging is subject to **Extended Producer Responsibility** (EPR) policies, meaning all components and complete packaging systems must be source-reduced, must comply with heavy-metals limits and minimization requirements for other noxious and hazardous substances, and must be recyclable, be compostable, and/or yield a certain energy gain when incinerated. The Packaging and Waste Directive[2] in Europe also mandates that companies selling products in Europe recover their product's packaging before it enters the waste stream. Many companies satisfy the requirements of the Directive by joining a "GreenDot" program (in Europe a total of 32 countries have national packaging compliance organizations that manage their country's packaging recovery programs).

Restrictions, bans, and phase-out limits also apply to certain materials, particularly expanded polystyrene (EPS) and polyvinyl chloride (PVC) in some jurisdictions and for certain product and packaging types. Several countries limit the percentage of empty space that may be contained within packaged consumer goods. Certain U.S. states require the use of recycled content materials in plastic packaging containers. In 2004, California's regulation was changed to require all rigid plastic packaging containers to comply regardless of the statewide recycling rate. And companies operating or trading in some markets must file periodic statements outlining packaging reduction efforts, goals, and progress toward existing goals.

In addition, there has been a recent surge in **take-back policies,** or regulations that require manufacturers to devise or fund a packaging recovery and recycling scheme. The Waste Electrical and Electronic Equipment (WEEE) and RoHS directives are the best-known sources of take-back regulations.

In many countries, fees are now imposed on packaged goods based primarily on the amount of packaging (by weight) and the type of packaging materials used. In general, the more packaging a product bears and the more difficult the packaging material is to recycle or manage in a given country, the higher the fees. Companies are required to calculate the quantities of each packaging material used and to file periodic reports—which, of course, requires detailed packaging data. For more detailed information about WEEE regulations and the RoHS Directive on take-back regulations, see www.dti.gov.uk/innovation/sustainability/weee/page30269.html and/or www.rohs.gov.uk/.

Clearly, engineers need to consider the full range of environmental issues related to packaging—across the full lifecycle of the product, across the entire supply chain—and be more creative in designing eco-effective packaging. But we must do so in a way that is economically practical, not just ecologically sensitive. We must find new ways to extract waste from the equation at the same time we devise better alternatives in terms of materials and production processes.

It is a common misconception that packaging design is typically an afterthought or a mundane chore for an engineer. Nothing could be further from the truth; in fact, the package design for many products can be far more ingenious than the product itself.

Consider the challenge of creating the packaging for Pop'n'Fresh dough. The mathematics involved in creating an airtight tube that will pop open easily when tapped against a hard surface—but not so easily that it will open prematurely in a refrigerator—would stagger many a rocket scientist. Even designing a cardboard box for shipping a refrigerator involves extremely complex calculations of "axial compression strength," formsboard options, paper grades, and post thicknesses to keep the refrigerator free from dents and scratches during shipment.

The point is that since packaging is already a sophisticated science, the time has come to apply a greater proportion of engineering ingenuity to eco-effective packaging. If we can optimize the axial compression strength of a refrigerator carton, surely we can reimagine the design, materials, and production processes to optimize for eco-effectiveness—throughout the product lifecycle, across the supply chain.

Waste and Renewal

The materials that go into product manufacture must be dealt with again when the useful life of the product is over. This section addresses the key considerations in designing for waste disposal and renewal: disassembly, reuse/recycling, and take-back.

Disassembly

In the past few years, a considerable amount of research has focused on designing products for disassembly and reusing/recycling their materials and components. Some of the key considerations for engineers include[3]

- Designing for easy disassembly and enabling the removal of parts without damage
- Labeling the parts so that people know what to do with them
- Ensuring that the purification process does not damage the environment
- Designing for ease of testing and classification
- Designing for reconditioning, or supporting the reprocessing of parts by providing additional material as well as gripping and adjusting features
- Providing easy reassembly for reconditioned and new parts

From the preceding list you see that disassembly plays an important role, not only in enabling parts and materials to be removed for recycling but also in enabling reconditioning, refurbishment, remanufacture, repair, and service of the product and components, extending their useful life.

Reuse/Recycling

Design for Recycling (DFR) initiatives are gaining momentum. It is becoming increasingly clear that it makes both economic and ecological sense to integrate end-of-life aspects into the design of products—particularly given the upward spiral in new legislation (e.g., packaging waste regulations such as the EU Packaging Directives, End of Life Vehicles [ELVs], and the WEEE Directive). Engineers are in a position to impact the recyclability of products because they directly control many of the key attributes:

- Material types, density, and so on
- Fastening—for example, the number and types of fasteners
- Architecture—for example, modularity, accessibility, and so forth

Engineers have been incorporating recyclable materials in many new-product designs for years. More recently a connection has been made between designing for disassembly and designing for recyclability. In both cases, the goal is to ensure that products are designed in a way that is as attractive as possible to recyclers. Making products quick and easy to disassemble helps.

Clearly, the specific issues and considerations for any DFR methodology will vary by product type, but we can suggest three starting points for understanding the key concepts and regulations pertaining to DFR.

- VDI 2243 is an effort from the German Engineering Society (VDI) to standardize notions about recycling. The purpose of VDI 2243 is to provide engineers with a quick and relatively complete overview of issues to be considered in designing products for recyclability. The guideline provides an introduction to recycling and discussions about production waste recycling, product recycling during a product's useful life, material and waste recycling after a product's useful life, and the application of DFR rules. It contains a wealth of information and illustrates the state of the art in design for recycling in Germany. The Web site www.vdi.de/ provides information about VDI 2243 in German; English and other translations are available through www.beuth.de/.
- You can find an excellent overview of issues to consider in designing for recyclability, prepared by the Georgia Institute of Technology Systems Realization Laboratory, at www.srl.gatech.edu/education/ME4171/DFR-Intro.ppt.
- "2007 Electronics Recycling: A Guide to International Regulations," by Kim Leslie,[4] provides a summary of regulatory developments in recycling and take-back worldwide, covering more than two dozen countries.

A recent example of how engineers can design for recyclability and create both ecological and economical benefits is provided by Subaru's assembly plant in Lafayette, Indiana. The plant was scheduled to produce 180,000 cars in 2008, and the automaker has pledged that virtually none of the waste generated from its output will wind up in a landfill.[5] This places significant focus on the supply chain, where most of the necessary improvements must be made. According to an article in *USA Today* (February 19, 2008), "Copper-laden slag left over from welding is collected and shipped to Spain for recycling. Styrofoam forms encasing delicate engine parts are returned to Japan for the next round of deliveries. Evan small protective plastic caps are collected in bins to be melted down to make something else. All told, Subaru says 99.8% of the plant's refuse is recycled or reused." The reuse effort on the Styrofoam inserts alone has saved the company $1.3 million per year, according to the article.

Take-Back

Producers have traditionally been responsible for the environmental impact of their production facilities, and they have borne the costs of pollution prevention (of course, they passed these costs on to customers). Downstream environmental impacts, however, have often been ignored. As a result, today the concept of EPR has emerged, making producers responsible for environmental impacts over the entire product lifecycle. That's the genesis of take-back policies, in which companies are required to collect and recycle products at the end of their useful life.

At this point, you can safely assume that most products will be subject to take-back legislation in most of the world within the next three to five years. Take-back legislation will provide numerical targets for collection, product recovery, and incineration, along with time frames for implementation. So, if you're starting a product design today, it's important to include this in your overall plan.

In many cases, a third-party company will handle the logistics of your company's take-back program, but make sure you capture the lessons learned so that you can apply them to the design of future products and services.

The initial targets for take-back legislation have been products that create a serious disposal problem in terms of volume or hazardous and toxic content; products for which there are no functioning or active secondary markets; and hazardous products for which the producer does not retain ownership through leasing contracts or other arrangements.

Already, considerable legislation on take-back is in effect or in the works. The European Union and Japan were among the first to introduce such legislation. In the United States, the first take-back law was passed in Maine in 2004. The WEEE Directive, effective in July 2006, makes manufacturers responsible for e-waste, based on recovery, recycling, and collection targets. The legislation is designed with two aims in mind: to create an economic incentive for manufacturers to design more environmentally friendly products, and to reduce the environmental impact of waste by increasing the volume that is recovered and recycled.

The goals for us as engineers will be to find new ways to take back our products with minimal customer costs; increase the "come-back" percentage; implement detailed data collection and reporting (e.g., percentage of products/materials ending up in the waste stream); and measure ongoing improvement in take-back processes.

Chemical and material choices can have both positive and negative business implications for product take-back.

- Substituting for potentially hazardous chemicals from a product can create market differentiation. One of the latest examples is the emergence of household paint products that avoid the use of volatile organic compounds (VOCs).
- Similarly, having hazardous chemicals discovered in your product may damage sales and brand credibility, as we've seen recently with a number of toys.
- Meeting local reporting and disposal regulations can be quite expensive. Avoiding materials that trigger these activities can result in potentially significant savings.

Markets for used materials continue to mature, and some materials, such as aluminum, can have significant value if they are clean. Don't assume that product take-back and processing represent only a cost; they may have the potential to produce income as well.