Chapter 4

Strategies for Green Design

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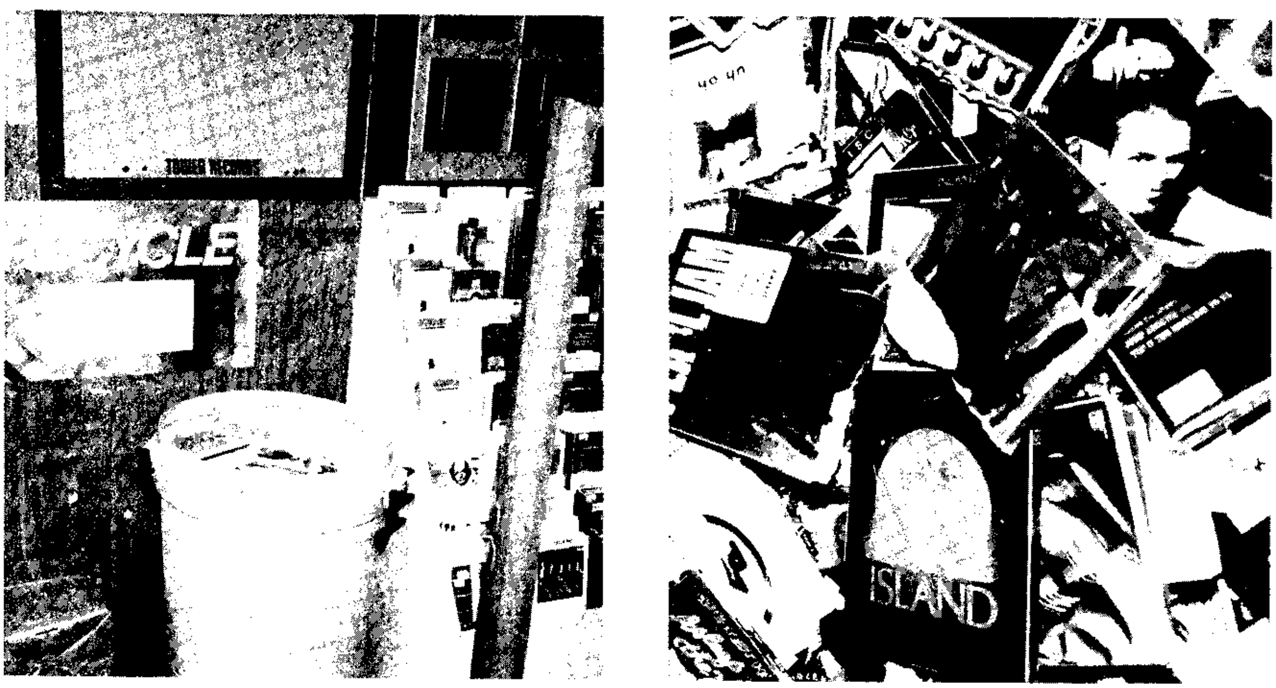

Photo credit: Tower Records

The "long box" package design for compact discs was developed to fit into existing LP record bins. The design has been criticized for its excess packaging. This example illustrates how product distribution systems can constrain design solutions. While some efforts are being undertaken to develop alternative designs that use less packaging, considerable industry resistance to anew package approach remains. Consequently, some retailers are initiating recycling programs to address consumer concerns.

Chapter 4

Strategies for Green Design

Designers do not in general have free rein in conceiving and developing products.[1] Some constraints relate to the products themselves: for example, marketing requirements, producer capabilities, and government regulations. Other constraints relate to the systems in which products must function. Numerous examples can be cited: compact disc package specifications are determined by the size of old record bins; software applications have to conform to operating system restrictions; movie cassettes are made in VHS format despite the apparent superiority of "Beta" technology.[2] It is therefore simplistic to encourage designers to "do the right thing" without considering the constraints they face.

In fact, design choices affect-and are affected by-extremely complicated production and consumption networks (see box 4-A). As might be inferred, these networks impose constraints on the designer that have important implications when attempting to integrate environmental objectives into the design process.

Accordingly, designers can use two different strategies to integrate environmental concerns into their choices of materials and processes. One, a product-oriented approach, is to optimize the environmental attributes of the product within the constraints of the existing production/consumption network. The second strategy, a systems-oriented approach, is to broaden the scope of optimization to include changes in the production/consumption network itself. The first option is easiest, since it can be accomplished within the context of an individual firm. The second is more ambitious, because it implies a new way of looking at products, and may require new patterns of industrial organization, such as the formation of cooperative relationships among suppliers, manufacturers, and waste management providers.

PRODUCT-ORIENTED GREEN DESIGN

In the product-oriented approach, designers begin with a product concept and develop a design solution within the framework of the existing production/consumption system. Designers might ask questions such as:

- What are the waste streams from alternative manufacturing processes?
- What substitutes for toxic constituents are available?
- How is the product managed after its disposal?
- How does the design affect recyclability?
- What are the environmental impacts of the component materials?
- How is the product *actually* used by consumers?

Answering these questions may involve significant extra effort on the part of designers, and may even require new company practices, such as changing cost accounting systems to explicitly reflect a product's environmental costs, or initiating waste stream audits. But many companies are accepting this challenge, and there appear to be significant near-term benefits that could result from widespread adoption of such a design approach. For instance, at a recent conference of packaging designers, there was a consensus that-with the commitment of upper management--companies could reduce the volume of their packaging by at least 10 percent in a single year through better design.[3] Since packaging typically accounts for around 30 percent of municipal solid waste (MSW) by volume, this would mean an overall reduction of 3 percent of MSW volume in 1 year from this source alone (and perhaps a significant reduction in the industrial waste stream as well).[4]

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[1] See the following Office of Technology Assessment contractor reports on the packaging, automobile, and electronics industries: Franklin Associates, "PackagingDesign and the Environment" April 1991; Frank Field, "Automobile Design and the Environment," May 1991; Chemcycle Corp., "Environmentally Sound Product Development in the Consumer Electronics and Household Battery Industries," July 1991.

[2] Recent work provides intriguing evidence that once a particular technology path is chosen, the choice may become ''locked-b" regardless of the advantages of the alternatives. See W. Brian Arthur, "Positive Feedbacks in the Economy," *Scientific American,* February 1990, pp. 92-99.

[3] Robert Hunt, Franklin Associates, personal communication, February 1991.

[4] In reality, these design changes would not all occur in a single year. Redesign can cost up to $1 million per package. Thus, manufacturers are likely to be most receptive to making changes in new package designs, or during the normal redesign cycle for existing packages.

Box 4-A—Networks

Technological advances in information technologies (computers, communications, etc.) are changing the nature of the U.S. economy, making it more complex and interdependent. These advances have led to the creation of elaborate networks that link consumers with retailers, retailers with manufacturers, and manufacturers with suppliers.[1] Virtually all sectors of the economy now depend on these production/consumption networks, with many of the networks being global in nature.[2]

As an example, consider the likely chain of events involved in the production and delivery of a frozen pizza. The pizza contains tomatoes from Mexico or California, and cheese from Wisconsin. Wheat for the pizza crust is grown in Kansas using sophisticated seeds and pesticides that are themselves the products of elaborate production networks. The pizza is assembled automatically with equipment from Germany, and wrapped in multilayered materials that are the result of considerable research and development. The pizza is probably purchased at a grocery store where a clerk passes it over a laser scanner (a device with components from Japan), which enters data into a computer and communication system designed to adjust inventories, restock shelves, and reorder products. This computer tracking system in turn makes it possible to operate an efficiently dispatched transportation system that places a premium on timely and safe delivery rather than on low bulk hauling charges. The checkout data is also used to analyze consumer response to the previous day's advertisements and to ensure that the store is closely following trends in local tastes. Any significant change in consumer buying patterns will quickly ripple throughout the production chain. So even in the case of a relatively simple product such as a pizza, the strong interconnections between disparate sectors of the economy become apparent.

Such tight linkages among industries present both opportunities and challenges for designers. Because of the flexibility they provide, networks can increase the range of possible product design options. For example, designers can choose from a wider base of materials or components suppliers. On the other hand, networks can create additional design constraints because of special distribution requirements, or greater variation in customer preferences. In many cases, networks can play a decisive role in shaping design solutions. Thus, to make significant environmental improvements, designers need to look beyond products and consider how networks themselves can be changed.

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1 See U.S. Congress, of&x of Technology Assessment, *Technology and the American Economic Transition: Choices for the Future*, OTA-TET-283 (Washington, DC: U.S. Government Printing Office, May 1988).

2 Organization for Economic Cooperation and Development, "The International Sourcing of Intermediate Inputs," Paris, January 1992.

SYSTEM-ORIENTED GREEN DESIGN

From an environmental perspective, it is simplistic to view products in isolation from the production and consumption systems in which they function. Is a fuel injector, for instance, a green product? From the vantage point of its component materials, probably not. But since it is designed to improve automobile fuel efficiency it could be considered "green' from a broader "systems" perspective.

Similarly, a computer, considered on its own, would probably not qualify as an environmentally sensitive product. The manufacture of a computer requires large volumes of hazardous chemicals and solvents, and heavy metals used in solder, wiring, and display screens are a significant contributor to the heavy metal content in landfills. But the same computer could be used to increase the efficiency of a manufacturing process, thus avoiding the use of many tons of raw materials and the generation of many tons of wastes. From this perspective, the computer is an enabling technology that reduces the environmental impact of the production system as a whole.

This illustrates an important Office of Technology Assessment (OTA) finding: green design is likely to have its largest impact in the context of changing the overall systems in which products are manufactured, used, and disposed, rather than in changing the composition of products per se. For instance, designing lighter fast-food packaging is well and good; but 80 percent of the waste from a typical fast-food restaurant is generated

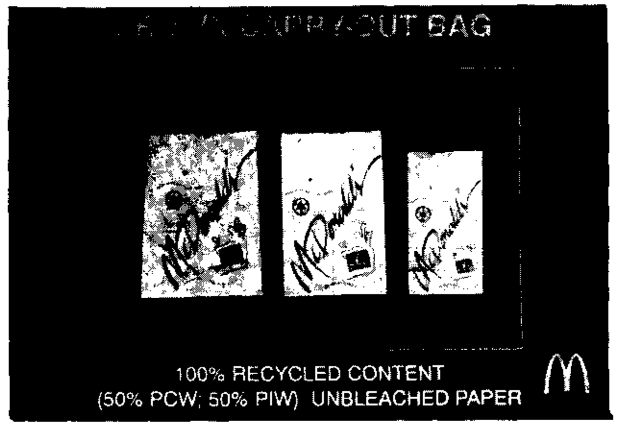


Photo credit: McDonald's Corp.

In cooperation with its suppliers, and with the assistance of the Environmental Defense Fund, McDonald's Corp. has implemented both waste reduction (left) and recycling (right) programs. By changing its sandwich packaging, McDonald's has reduced its "behind-the-counter" waste (e.g., smaller corrugated boxes) as well as Its post-consumer waste.

behind the counter, where consumers never see its Addressing this larger problem requires that designers establish cooperative relationships with their suppliers and waste management providers to manage materials flows in an environmentally sound way.

Product design that accounts for the dynamic relationships among *all* companies involved in a production system has the potential to produce less waste than product design that only takes account of an individual company's waste stream. The study of the relationships among firms in production networks, and the effects of these relationships on the flow of energy and materials through our society, is an emerging field called ''industrial ecology" or ''industrial metabolism."[6]

The opportunities for linking product design with system-oriented thinking have not been fully explored, but examples are beginning to appear in different sectors of the economy. For instance, pesticide use has declined dramatically where farmers have adopted integrated pest management schemes involving crop rotation, and the use of natural predators.[7] Due to the success of these new methods, chemical companies are no longer simply supplying pesticides to farmers, but are also providing expertise on how to use those chemicals in conjunction with better field design and crop management. Similarly, in the energy supply sector, utilities are providing energy audit services, and are promoting customer use of energy-efficient equipment, instead of building new generating plants (see box 4-B).

A systems approach to design thus involves a unified consideration of production and consumption activities: supply-side and demand-side requirements are treated in an integrated way. This is a more far-reaching design approach in which designers might ask:

- How would new supplier and customer relationships affect the management of product materials throughout their life cycle?
- How could the same consumer need be fulfilled in a "greener" way (i.e., thinking about a product in terms of the service it provides, rather than as a physical object)?
- How could other companies' waste streams be used as process inputs?

5 For example, about 35 percent of the waste generated by McDonald's restaurants is corrugated boxes, and another 35 percent is food scrap. To address these problems, McDonald's, in cooperation with the Environmental Defense Fund, has been examining the dynamics of its food distribution and production systems. By working with its suppliers to change delivery methods, and by developing comporting strategies, McDonald's is taking steps to reduce these large "behind-the-counter" wastes. See the "Final Report of the Environmental Defense Fund/McDonald's Corporation Waste Reduction Task Force," Washington DC, April 1991.

6 Proponents of industrial ecology envision systems of production that would emulate the web of interconnections found in the natural world. See "Colloquium on Industrial Ecology," *Proceedings of the National Academy of Sciences,* vol. 89, No. 3, Feb. 1, 1992, pp. 793-884; and Robert Ayres, "Industrial Metabolism," *Technology and Environment* (Washington, DC: National Academy Press, 1989), pp. 23-49.

7 See U.S. Congress, Off&of Technology Assessment, *Beneath the Bottom Line: Agricultural Approaches To Reduce Agrichemical Contamination of Groundwater, OTA-F-418* (Washington, DC: U.S. Government Printing Office, November 1990), pp. 115-118.

Photo credit: GE Plastics

A refillable bottling system can offer significant energy and materials savings in comparison with nonreturnable beverage containers. The impact-resistant, lightweight polycarbonate bottles shown here can be reused up to 50 times. Institutional users of refillable bottle systems, such as schools, have in some cases reduced solid waste volume by 50 percent.

- How might product design changes alter the waste stream so that it could become a useful input into another industrial process (i.e., wastes should be regarded as potential products, not just residuals of a particular industrial process)?

If the potential environmental benefits of a system-oriented approach are greater, then so are the challenges. The creation of new networks of production or distribution may be required, and long-standing relationships among manufacturers and suppliers may have to change. Such changes are not generally within the purview of product designers, and millions of dollars may be invested in the existing infrastructure for production and distribution. A systems design approach implies an unprecedented elevation of product design to the level of strategic business planning, and a new way of thinking about the environment at the highest echelons of a corporation.

Incentives for System-Oriented Green Design

There may appear to be few incentives for industry to consider such dramatic changes in existing production networks.[8] But changes of comparable magnitude are already underway. Many manufacturers are rethinking their business relationships with suppliers and customers in order to implement total quality management and concurrent engineering programs.[9] The traditional adversarial relationship between manufacturers and suppliers is giving way to a more cooperative business paradigm.[10]

General Motors, for example, has adopted an approach where it relies on a single supplier for its chemical requirements. A single chemical firm, rather than a group of suppliers, is chosen to provide, coordinate, and manage all the chemical needs of a plant and to provide continuous, on-site technical support. The supplier is remunerated according to the productive output of the plant. The supplier's profits are thereby based on the services it provides to meet a factory's production requirements, rather than the amount of chemicals sold. This cooperative strategy has reduced chemical usage by approximately 25 percent within GM facilities.[11]

The formation of environmental networks among producers, suppliers, and waste management providers could allow industry to more effectively address environmental problems. Integrated networks, in

8 In fact, in some cases, there may exist regulatory disincentives. For example, it is the view of many in industry that the Resource Conservation and Recovery Act (RCRA) has impeded the reuse of spent materials. When a hazardous material falls out of a given manufacturing process, it becomes by legal definition a "waste," and is subject to stiff regulation. Because of potentially significant liability penalties, the effect of this regulation is to limit any further industrial uses of the material, and by default, the material really does become a waste. See Institute of Scrap Recycling Industries (ISRI), testimony of Herschel Cutler before the Subcommittee on Environmental Protection of the Senate Committee on Environment and Public Works, June 1991. Also see Braden Allenby, "The Design for Environment Information System," an interim report prepared for the Rutgers University Environmental Science Department, 1991.

9 See 'A Smarter Way To Manufacture," *Business Week,* Apr. 30, 1990; Genichi Taguchi and Don Clausing, "Robust Quality," *Harvard Business Review,* January-February 1990; Daniel Whitney, "Manufacturing by Design,'' *Harvard Business Review,* July-August 1988; "Concurrent Engineering," *IEEE Spectrum,* July 1991, p. 22; "Manufacturing: The New Case for Vertical Integration" *Harvard Business Review,* March-April 1988; "Stress on Quality Lifts Xerox's Market Share," New *York Times, Nov. 9, 1989,* p. D1.

10 See U.S. Congress, Office of Technology Assessment, *Making Things Better: Competing in Manufacturing,* OTA-ITE-443 (Washington, DC: U.S. Government Printing Office, February 1990), p. 129.

11 John Ogden, General Motors, personal communication, July 3, 1991.

Box 4-13-Designing a Green Energy System: Demand-Side Management

Faced with rising demand, spiraling construction costs, and strict pollution control laws, some electric utilities are trying a new strategy: they are convincing customers to buy less electricity. The strategy may seem strange, but it employs some of the central ideas of green design. In the end, it helps customers, the environment, and, surprisingly, the utilities themselves.

The strategy is known as demand-side management (DSM)---a set of techniques intended to alter how a utilitys customers use electricity. Utilities using DSM do more than meet the electricity demands of their customers, they also help customers reduce or better distribute that demand. Examples of DSM include low-interest bans or rebates to homeowners who install energy-efficient heat pumps and compact fluorescent lights, and free energy audits. Like many innovative efforts at green design, DSM focuses on services, rather then goods; it encourages utilities to focus on the services provided by electricity (e.g., heating and lighting), rather than on electricity itself.

While environmentally desirable, DSM seems an unlikely strategy for a utility to pursue. Electric utilities operate as regulated monopolies, and their profits traditionally depend on sales. However, regulators in more than *30* States have adopted provisions to financially reward utilities for DSM activities. Many of these incentives treat DSM as an investment rather than an expense, allowing utilities to earn returns in the same way they do from powerplants. These regulatory incentives, coupled with high construction costs and strict pollution control laws, make DSM an attractive alternative to building new generating plants.

To influence electricity demand, many DSM programs encourage the use of energy-saving technologies. According to studies from the Electric Power Research Institute (EPRI) and the Rocky Mountain Institute, widespread adoption of these technologies could reduce total electricity demand by 24 to 75 percent. However, utility customers are often slow to adopt energy-efficient technologies, even though they provide long-term financial benefits. Customers may face institutional or financial barriers, or they may lack information on potential savings. DSM programs aim to provide information and incentives to overcome these barriers.

While DSM itself is directly applicable only to regulated utilities, its success demonstrates how economic incentives can affect large, often conservative, organizations. Some utilities undertook DSM because of its positive public relations value, but many others responded to provisions that allow them to profit directly from DSM programs. The success or failure of DSM programs may point the way toward government programs that can influence individuals and companies to adopt ''green' technologies.

SOURCES: U.S. General Accounting Office, “Electricity Supply: Utility Demand-Side Management Programs Can Reduce Electricity Use,” October 1991. Paul Klebnikov, “Demand-Side Economics,” Forbes, Apr. 3, 1989, pp. 148-150. Leslie Lamarre, “Shaping DSM as a Resource,’ *EPRI Journal, October/November 1991, pp. 4-15.*

essence, expand the scale of a firm’s operations and permit a firm to consider design solutions that would otherwise not be possible. In the housing industry, for example, an alliance of companies, the Integrated Building and Construction Companies (IBACoS) consortium, is developing new home concepts that promote energy and materials efficiency (see box 3-B). Ultimately, tighter inter-industry linkages could encourage the creation of closed-loop industrial systems where manufacturing byproducts from one industry are used as inputs for other industrial processes.

In Kalundborg, Denmark, an “industrial ecosystem’ has been created where manufacturing wastes, surplus energy, and water are traded among a variety of different economic actors. This cooperative arrangement in energy and materials management involves a powerplant, a plasterboard maker, a cement factory, a pharmaceutical firm, an oil refinery, a collection of farmers, and the local heating utility .12 Similar, but less elaborate efforts have been undertaken in the United States. In past years, Meridian National, an Ohio steelmaker, has sold its waste ferrous sulfate to magnetic tape manufacturers. Also, the Atlantic Richfield oil company has sold its spent silica catalysts to cementmakers. If they had not been sold, these materials would have been disposed as hazardous wastes.[13]

Product Take-Back and the Rent Model

New government regulations giving manufacturers responsibility for the environmental fate of their products are also likely to bring about systems-based

12 See ‘‘A Rebirth of the Pioneering Spirit,” *Financial Times, Nov.* 11, 1990, p. 15.

13 See Robert Frosch and Nicholas Gallopoulos, “Strategies for Manufacturing,” *Scientific American,* September 1989, pp. 144-152.

design solutions. For example, Germany's proposed law requiring automakers to take back and recycle automobiles has stimulated the German automobile industry to develop new cooperative strategies for auto design, manufacturing, and recycling (see box 4-c).

Perhaps the ultimate extension of the manufacturer take-back concept is the "rent model," in which manufacturers retain ownership of products and simply rent them to customers. This gives manufacturers incentives to design products to maximize product utilization, rather than simply sales.[14]

This idea was implemented in the telephone industry for many years. Before divestiture, AT&T leased virtually all telephones and thus was able to readily collect them. AT&T designed its phones with a 30-year design lifetime, and collected almost every broken or used telephone. The phones were either refurbished or were processed for materials recovery. However, with the end of AT&T's regulated monopoly and the creation of a competitive market, the number of telephone manufacturers dramatically increased. Consumers were given a wide variety of product choices. The number of phones purchased by consumers, as opposed to leased from the Bell System, grew rapidly. Accordingly, the proportion of telephones that were thrown away rather than fed back to the Bell System also increased, with a corresponding drop in the number of units available for reuse or recycling. It is estimated that approximately 20 to 25 million phones are now disposed of each year.[15]

This concept of selling *product utilization* rather *than products per se* currently applies to a variety of durable goods. Computers, copiers, aircraft, and sophisticated medical equipment are being leased rather than sold to customers. For example, Xerox leases copiers on 'a "total satisfaction guarantee" basis, where customers pay a certain fee for each copy and do not have to take responsibility for product operation. Some of the latest machines are even equipped with communication lines to service centers to allow automatic equipment monitoring. By retaining ownership of the products they lease, companies have a strong incentive to design goods so that they can be reused or remanufactured. In some firms it has caused a fundamental reassessment of design procedure.

When a product is viewed as an agency for providing a service or fulfilling a specific need, the profit incentive changes; income is generated by optimizing the utilization of goods rather than the production of goods.[16] While the fundamental goal of a firm would still be profit maximization, this objective could be met by marketing services as well as products. As an illustration, when a large Swiss chemical company began selling guarantees of "pest-free" fields instead of pesticides, it was able to maintain previous profit levels while reducing pesticide usage by 70 percent.[17] Thus, instead of selling as much pesticide as possible to customers, it sold a systems solution. In essence, services were substituted for chemicals.

The notion of thinking about a product in terms of the function it performs is a logical extension of total quality management (TQM) philosophy. The aim of total quality management is to satisfy customer needs. Customers usually do not care how their needs are met, as long as they are indeed met. Thus, it should not matter whether a customer's requirements are satisfied by a specific product, or by a service performed in lieu of that product.

Although the renting versus selling idea offers the possibility of reducing resource consumption rates while still meeting the needs of consumers, its range of applicability may be limited. It may work better on the corporate level than on the level of individual consumers. Average consumers may be reluctant to purchase used or refurbished goods, and divorcing products from consumer ownership could result in more careless use of those products. This model is probably more appropriate for high-value, durable products than for nondurable or disposable products.

14 Walter Stahel, The Product-Life Institute, Geneva, personal communication, Nov. 8, 1991. For more on this idea, see Orio Giarini and Walter Stahel, *The Limits to Certainty: Facing Risks in the New Service Economy* (Boston, MA: Kluwer Academic Publishers, 1989).

15 Braden Allenby, Senior Attorney, AT&~ personal communication, Sept. 13, 1991.

16 Stahel, op. cit., footnote 14.

17 Ibid.

Box **4-C—Design** *and Materials Management in the Auto Industry*

When an old car is junked, it is often first sent to a dismantle, who removes **any** parts that can be resold, as well as the battery, tires, gas tank, and operating fluids. The hulk is then crushed and sent to a shredder, which tears it into fist-sized chunks that arc subsequently separated to recover the ferrous and nonferrous metals.

Presently, about 75 percent by weight of materials in old automobiles (including most of the metals) are recovered and recycled. The remaining *25* percent of the shredder output, consisting of one-third plastics (typically around 220 pounds of 20 different types), one-third rubber and other elastomers, and one-third glass, fibers, and fluids, is generally landfilled. In the United States, this shredder "fluff' amounts to about 1 percent of total municipal solid waste. Sometimes, the fluff is contaminated with heavy metals and oils, or other hazardous materials.

As automakers continue to search for ways to improve fuel efficiency and reduce manufacturing costs, the plastic content of cars is expected to increase. This will not only increase the amount of shredder fluff sent to landfills, it threatens the profitability of shredder facilities, which currently depend on metals recovery to make money.

In Germany, the landfilling of old automobile hulks and the shredder residues from automobile recycling operations is a growing problem, The German Government has proposed legislation that would require automakers to take back and recycle old automobiles at the end of their lifetime. This has stimulated German automakers to explore fundamental changes in automobile design that could result in more efficient materials management, These changes would involve new relationships among auto manufacturers, dismantles, and materials suppliers.

To avoid dealing with the auto hulks themselves, the automakers propose to take better advantage of the existing infrastructure for auto recycling, Manufacturers will design cars that can be more cheaply disassembled, and will educate dismantles as to how to efficiently remove plastic parts. They will encourage their material suppliers to accept recovered materials from dismantlers, and will specify the use of recovered materials in new car parts, thus "closing the loop."

Green automobile design within this new framework of coordinated materials management has a very different character than auto design within an isolated firm. Instead of just thinking about how to design a fender or bumper using 10 percent less material, the designer also thinks about how the fender or bumper can be constructed from materials that can be co-recycled, and readily separated from the car body.

Several German companies, including BMW and Volkswagen, have begun to explore this system-oriented approach. BMW recently built a pilot plant to study disassembly and recycling of recovered materials, and Volkswagen AG has constructed a similar facility. The goal of the BMW facility is to learn to make an automobile out of 100 percent reusable/recyclable parts by the year 2000. In 1991, BMW introduced a two-seat roadster model whose plastic body panels are designed for disassembly, and labeled as to resin type so they may be collected for recycling.

Interest in improving materials management in the auto industry is not limited to Europe. Japan's Nissan Motor Co. has announced research programs to explore design for disassembly, to reduce the number of different plastics used, to label those plastics to facilitate recycling, and to use more recovered materials in new cars. In the United States, Ford, Chrysler, and General Motors plan to label plastic components to identify the polymers, and have recently established a consortium with suppliers and recyclers (called the Vehicle Recycling Partnership) to address the recycling issue.

Autos are already one of the most highly recycled products in the United States, This success is largely due to the efficiency of shredder technology; a single facility can process up to 1,500 hulks per day. This level of productivity is not consistent with labor-intensive disassembly operations. Although research on recycling automotive plastics is ongoing, it is not yet economically feasible to separate and recycle these materials, even when avoided landfill tipping fees are included. Thus, it seems clear that a change in materials management in the U.S. auto industry is unlikely to emerge without substantial new economic or regulatory incentives.

SOURCE: Officc of Technology Assessment, 1992.

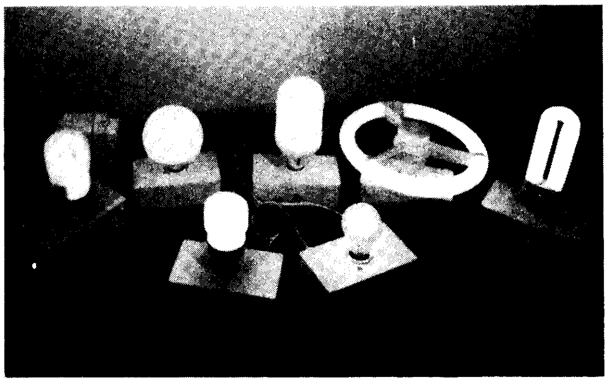


Photo credit: U.S. Department of Energy

Compact fluorescent bulbs, which are available in a variety of designs, use 75 percent less energy than standard incandescent lamps, but contain small amounts of mercury. The mercury produces the ultraviolet radiation that causes fluorescence.

MEASUREMENT ISSUES

Measuring Product-Oriented Green Design

With all of the choices available, how can designers and consumers determine what a' 'green' product is? As discussed in chapter 2, there maybe design tradeoffs among alternative environmental attributes of a product—for instance, between waste prevention and recyclability. As an illustration, 3 pounds of a multilayered "polyester brick" packaging material can deliver the same amount of coffee as 20 pounds of metal.[18] Unlike the metal can, the polyester brick is not currently recyclable. However, to achieve equivalent levels of waste, a recycling rate of 85 percent for the metal can would be required, far higher than current rates.

Tradeoffs may also exist between other environmental attributes, such as toxicity and energy efficiency. For example, the new high temperature superconductors, which potentially offer vast improvements in power transmission efficiency, are quite toxic; the best of them is based on thallium, a highly toxic heavy metal. Similarly, the use of compact fluorescent bulbs in lieu of incandescent bulbs can result in substantial energy savings.[19] But compact fluorescent lamps contain small amounts of mercury.[20] In this case the use of a toxic substance has measurable environmental benefits.

Life-Cycle Analysis

The existence of these tradeoffs highlights the need for analytical tools for weighing the environmental costs and benefits of alternative design choices early in the design process. One methodology that is receiving increasing attention is product life-cycle analysis (LCA). LCAs attempt to measure the "cradle-to-grave" impact of a product on the ecosystem.[21] In principle, LCAs could be used *in the design process* to determine which of several designs may leave a smaller "footprint" on the environment, or *after the fact* to identify environmentally preferred products in government procurement or eco-labeling programs.[22]

Conceptually, the life-cycle approach has helped to illuminate the environmental impacts of some products that had not been considered before, especially the ''upstream" impacts associated with material extraction, processing, and manufacturing. By comprehensively accounting for materials inputs and outputs, LCAs can keep track of impacts that are merely shifted from one stage of the life cycle to another, or from one environmental medium to another. Qualitative LCAs are already being used by some companies as an internal design tool to help identify the environmental tradeoffs associated with design decisions. The life-cycle perspective also seems essential for a credible eco-labeling scheme. The first step is to develop an inventory of the

18 The brick consists of polyester, aluminum foil, nylon, and low-density polyethylene laminated together. It should be noted that the coffee brick was developed to preserve product freshness, and not because of environmental considerations. See Franklin Associates, op. cit., footnote 1.

19 Over a 10,000-hour period, *one* 18-watt fluorescent lamp replacing a 75-watt incandescent lamp results in energy savings of 570 kilowatt hours. This translates into approximately 500 fewer pounds of coal consumed, and 1,600 pounds less carbon dioxide released. Paul Walitsky, Manager Environmental Affairs, Philips Lighting Co., personal communication, May 1991.

20 A compact bulb typically contains about 5 mg of mercury. The mercury, when vaporized in the lamp's electric arc, produces the ultraviolet radiation that causes fluorescence. (There are some data that indicate that the amount of mercury released from coal combustion for electricity generation exceeds the amount of mercury that would be used if incandescent bulbs were systematically replaced by compact fluorescent). Ibid.

21 Ideally, the analysis consists of three steps: an inventory of resource inputs and waste outputs for each stage, an assessment of the risks associated with these inputs and outputs, and an assessment of possible options for improvement. However, virtually all LCAs attempted to date have consisted only of the first step. See Society of Environmental Toxicology and Chemistry, ''A Technical Framework for Life-Cycle Assessments,' Washington, DC, January 1991.

22 ''Eco-labels'' are environmental seals of approval that are awarded to products whose manufacture, use, and disposal have fewer impacts on the environment than comparable products.

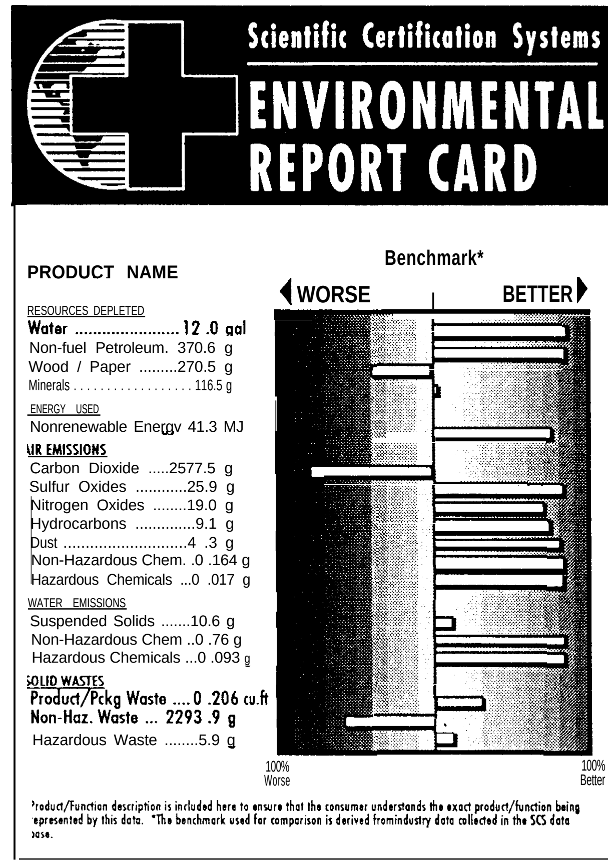
resource inputs and waste outputs over the entire life cycle. One approach to collecting and displaying this information is shown in figure 4-1.

If an accurate inventory can be assembled, this can provide preliminary insights into the environmental attributes of a product. But to determine definitively whether one product is "greener" than another, it is also necessary to know how the quantities in figure 4-1 should be weighted to reflect their relative health and environmental risks. For example, how should a pound of sulfur dioxide emitted to the air during manufacture be compared with a pound of solid waste going to the landfill? Is it more desirable to use laundry detergents that contain phosphates or phosphate-free detergents that release volatile organic compounds? To resolve such questions, additional information about environmental fate, exposure pathways, and dose-response data for each environmental release is required.

Another serious limitation is that the data requirements of a comprehensive LCA can quickly get out of hand. A major problem is where to draw the boundaries of the analysis. Can certain materials and energy flows be ignored without overlooking some significant environmental effects? For example, should one consider the energy required to produce the fertilizer that is used to grow the cotton that is used in cloth diapers? And if the energy is derived from coal as opposed to hydroelectric power, should one count the sulfur dioxide emissions associated with the combustion of coal?[23] Moreover, data uncertainty can be compounded by the fact that life-cycle analysis is sensitive to changes in inputs over time. If a few material or technology inputs change, initial assumptions may no longer hold, and the inventory might require a complete updating. When applied to more complicated products like televisions and automobiles, the LCA methodology might become hopelessly difficult to implement. Precisely because LCAs are multidimensional, interest groups are free to emphasize the aspects most favorable to their own agendas, thus providing almost limitless potential to confuse consumers.[24]

Before LCAs (inventory and risk assessment) can become a complete tool for comparing the greenness

Figure 4-l-Life-Cycle Inventory



One approach to reporting the results of a life-cycle inventory is illustrated by this hypothetical comparison of a product against a benchmark product. For each product, the resource depletion, energy consumption, air emissions, water emissions, and solid wastes associated with manufacture and product use are tabulated. The inventory approach shown here will be used by SCS in lieu of a simple eco-label.

SOURCE: Scientific **Certification Systems.**

of products after the fact, these issues will have to be resolved. Less information will probably be required, not more. LCAs may have to be streamlined to focus on a few critical dimensions of a product's environmental impact, rather than all dimensions. One possibility might be to limit the analysis to three dimensions: a product's contribution to catastrophic or irreversible environmental impacts (e.g., ozone destruction, species extinction), acute hazards to human health, and life-cycle energy consumption.

23 These methodological issues will be discussed in the upcoming Environmental Protection Agency report, "Life-Cycle Assessment: Inventory Guidelines and Principles," Battelle and Franklin Associates, contractor report for U.S. EPA Office of Research and Development.

24 "Life-Cycle Analysis Measures Greenness, But Results May Nol Be Black and White," *Wall Street Journal,* Feb. 22, 1991, p. B1.

Any such "partial" LCA can be criticized as being incomplete; for example, according to the criteria above, chronic health effects of long-term exposure to low concentrations of chemicals would not be considered. But some such simplification seems essential if LCAs are to be widely used.

There are further difficulties. Because they are inherently product-focused, LCAs are consistent with the product-oriented design approach. But in focusing attention on the environmental attributes of products *per se, the* LCA approach to design may divert attention from larger opportunities available by designing products in concert with new systems of production, consumption, and waste management.[25] Fundamentally, LCAs are "static" in that they provide a snapshot of material and energy inputs and outputs in a dynamic production system. LCAs therefore do not capture the opportunities for new technologies and new production networks to reduce resource use and wastes. In assuming that the product will be offered with certain characteristics to perform a certain service, LCAs may limit the scope of designers to consider ways of providing the service in more environmentally sound ways.

In the near term, life-cycle comparisons of products are likely to be limited to comparisons of resource and waste inventories. For designers' purposes, the inventory need not be exhaustive to be useful. For the purpose of product labeling, the inventory should be rigorous, easily verifiable, and periodically updated. Even so, at best, the inventory will clarify environmental tradeoffs, rather than provide definitive conclusions.

Measuring System-Oriented Green Design

How do we measure the environmental impact of alternative systems, as opposed to alternative products? Product characteristics are tangible and can—at least in principle-be quantified through life-cycle analysis; systems characteristics are less tangible. To measure the environmental performance of systems (say, transportation systems or telecommunication systems), new metrics will be required. Perhaps aggregate indicators like "energy intensity' and "materials intensity" could be used to compare "green systems."[26]

Another useful aggregate measurement tool might be provided by input-output analysis. Input-output analysis models the exchanges (inputs and outputs) between producers and suppliers. It can be used to examine the exchanges among a small group of companies, or the workings of national economies. In principle, input-output techniques could be used to correlate both intermediate and final products with emissions of various pollutants.27 Using these models, it might be possible to track the pollution associated with alternative production networks.

With an emphasis on service, we may be more concerned about product utilization rates rather than disposal rates or quantities of emissions. For instance, a measure of environmental performance might be product lifetime, or how effectively a product performs its designated task (e.g., the efficacy of a pesticide as part of an integrated pest management scheme). Credible measurement tools to evaluate the environmental performance of networks are an important research topic for the future, as discussed in chapter 6.

SUMMARY

Green design thinking can occur on several levels. At the product level, designers can optimize designs so as to improve materials and energy efficiency, or product longevity. A more ambitious approach is to think about how product designs might be optimized in a context of reorganized production and consumption systems. Such an approach suggests a design philosophy that places primary emphasis on the service a product provides rather than the product itself. Thus, systems solutions require real behav-

~ Is it correct to consider the LCA results of a particular product in isolation from the ripple effects of that product in the economy? The environmental externalities associated with a product might be outweighed by the greater efficiencies achieved when that product is incorporated into other products; a good example would be computer chips and the automated systems that use those chips to improve manufacturing efficiency.

26 Energy intensity refers to the Btus used to produce a dollar's worth of gross domestic product (GDP); materials intensity refers to the quantities of materials (metals, lumber, cement, etc.) used to produce a dollar's worth of economic output. In recent decades, both energy intensity and materials intensity in the United States have declined. See U.S. Congress, Office of Technology Assessment, *Energy Use and the U.S. Economy, OTA-BP-E-57* (Washington, DC: U.S. Government Printing Office, June 1990); and Eric Larson, Marc Ross, and Robert Williams, "Beyond the Era of Materials," *Scientific American,* June 1986, pp. 34-41.

27 With the availability of mandated databases on industrial waste streams such as EPA's Toxics Release Inventory, it is becoming feasible to incorporate pollution data into these economic models. See Faye Duchin, "Industrial Input-Output Analysis: Implications for Industrial Ecology," op. cit., footnote 6, pp. 851-855.

ioral change on the part of producers and consumers, and can be difficult to implement. However, if the systems in which products are manufactured, used, and disposed can be modified, the environmental benefits will likely go well beyond what is possible by focusing on products alone.