Chapter 2

Environmental Aspects of Materials Use

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The world economy is consuming resources and generating wastes at unprecedented rates. In the past 100 years, the world's industrial production increased more than 50-fold,[1] releasing some materials to the environment at rates that far exceed releases occurring naturally. Human activities are estimated to release several times as much chromium, nickel, arsenic, and selenium to the atmosphere as do natural processes, and over 300 times as much lead.[2] Carbon dioxide levels in the atmosphere are increasing at a rate 30 to 100 times faster than the rate of natural fluctuations observed in the climatic record.[3]

The U.S. economy is among the most material intensive economies in the world, extracting more than 10 tons (20,000 lb) of "active" material per person from U.S. territories each year.[4] Most of this material becomes waste relatively quickly. By one estimate, only 6 percent of this active material is embodied in durable goods; the other 94 percent is converted into waste within a few months of being extracted.[5]

These statistics on material flows do not directly measure the increased risks to human health or ecosystems, but recent experience with ozone depletion and the threat of global warming indicates that such explosive growth in materials flows could have profound and possibly irreversible environmental consequences. This growth is expected to continue; by the middle of the next century, the world population is expected to double,[6] and the global economy could be five times as large.[7]

The environmental risks posed by increasing materials flows can be addressed both by improving industrial efficiency and by substituting less damaging materials for those currently in use. For example, substitutes for chlorofluorocarbons (CFCs) are becoming available as the production of these ozone-depleting chemicals is phased out. However, such actions tend to be taken only in direct response to government regulations or after some specific environmental problem has reached threatening dimensions. Industrial production decisions have generally not considered the environmental impacts of materials and process choices in a proactive way.

HOW PRODUCT DESIGN AFFECTS THE ENVIRONMENT

Product design decisions have impacts on the environment at each stage of the product life cycle, from extraction of raw materials to final disposal (figure 2-1). Ideally, one would like design decisions to take account of both the "downstream" impacts (product use and disposal) as well as the "upstream" impacts (materials extraction, processing, and manufacturing).

The most publicly visible environmental impacts associated with products are the "downstream" impacts, particularly municipal solid waste (MSW). U.S. households and commercial establishments generate about 4 pounds of trash per person each day. In 1988, the United States generated some 180 million tons of MSW (figure 2-2). This amount is expected to increase by about 1.5 percent per year, resulting in total MSW generation of over 215

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[1] Baaed on data from W.W. Rostow, *The World Economy: History and Prospects* (Austin, TX: University of Texas Press, 1978), pp. 48-49.

[2] James N. Galloway, J. David Thornton, Stephen A. Norton, Herbert L. Volchok, and Ronald A.N. McLean, *Atmospheric Environment* 16(7):1678, 1982. See also Robert U. Ayres, "Toxic Heavy Metals: Materials Cycle Optimization" *Proceedings of the National Academy of Sciences*, vol. 89, No. 3, Feb. 1, 1992, pp. 815-820.

[3] U.S. Congress, Office of Technology Assessment, *Changing by Degrees: Steps To Reduce Greenhouse Gases*, OTA-O-482 (Washington, DC: U.S. Government Printing Office, February 1991), p. 45.

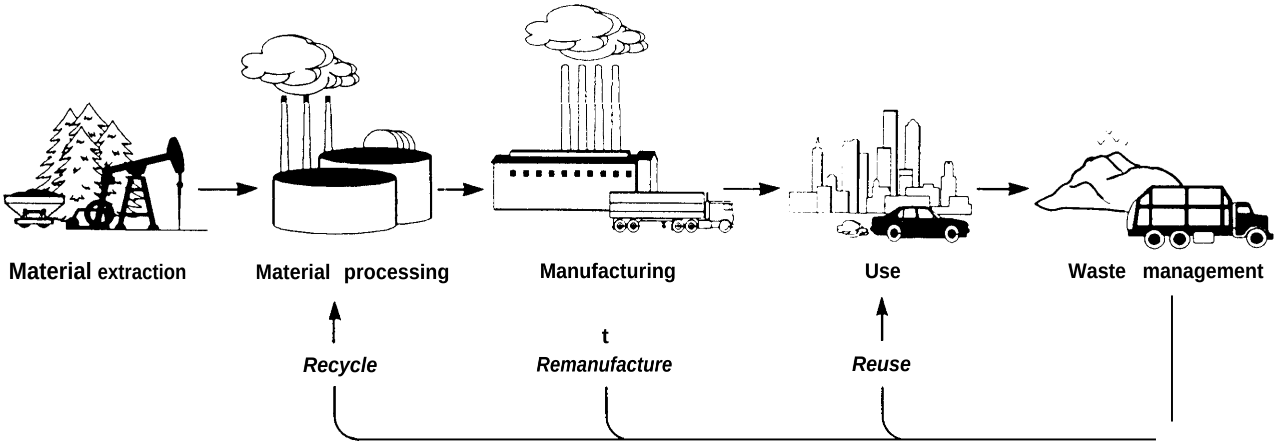
[4] "Active" material includes food, fuel, forestry products, ores, and nonmetallic. It excludes inert *construction* materials such as sand, gravel, and stone, as well as atmospheric oxygen and fresh water. Robert U. Ayres, "Industrial Metabolism," *Technology and Environment* (Washington DC: National Academy Press, 1989), p. 25.

[5] Ibid., p. 26.

[6] United Nations, Department of International Economic and *Social Affairs, Long-Range World Population Projections: Two Centuries of Population Growth 1950-2150 (New* York, NY: United Nations, 1992), p. 14.

[7] George Heaton, Robert Repetto, and Rodney Sobin, *Transforming Technology: An Agenda for Environmentally Sustainable Growth in the 21st Century* (Washington, DC: World Resources Institute, April 1991), p. 1.

Figure 2-l-Stages of the Product Life Cycle



Environmental impacts occur at all stages of a product's life cycle. Design can be employed to reduce these impacts by changing the amount and type of materials used in the product, by creating more efficient manufacturing operations, by reducing the energy and materials consumed during use, and by improving recovery of energy and materials during waste management.

SOURCE: Adapted from D. Navinchandra, The Robotics Institute, Carnegie Mellon University, personal communication, March 1992.

million tons by the year 2000.[8] Landfills in many States are reaching their permitted capacity, and there is increasing public opposition to siting new waste management facilities. One major reason for this opposition is concern about toxic materials released from these facilities, e.g., when batteries are incinerated, or when household hazardous waste is placed in landfills.

Less visible but potentially more serious environmental impacts occur during raw material extraction, material processing, and product manufacturing. U.S. industry generates some 700 million tons of "hazardous waste" and some 11 *billion* tons of ''non-hazardous' solid waste.[9] Although the weight of industrial and municipal solid waste cannot be compared directly,[10] industrial wastes dwarf municipal solid wastes in their quantity and environmental impact (see figure 2-3).[11] Product design decisions have a direct influence on the manufacturing component of these wastes (about 6.5 billion tons).

Finally, some of the most serious environmental releases occur during the actual use of the product. This is particularly true of products that are consumed or dissipated during their use (e.g., volatile solvents and propellants, fuels, cleaners and paints, and agricultural fertilizers and pesticides).[12] Prime examples are CFCs used as coolants, solvents, and

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[8] U.S. Environmental Protection Agency, *Characterization of Municipal Solid Waste in the United States: 1990 Update,* June 1990, pp. ES-3 and 75; U.S. Congress, Office of Technology Assessment, *Facing America's Trash: What Next for Municipal Solid Waste, OTA-0+24* (Washington DC: U.S. Government Printing Office, October 1989).

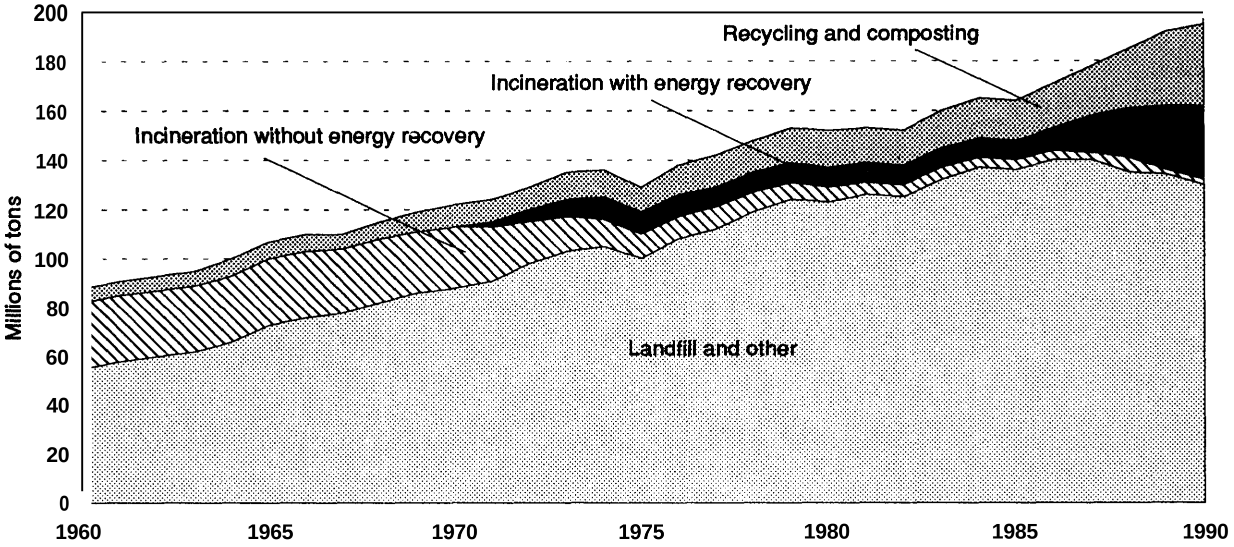
[9] *The terms hazardous* and *non-hazardous are* defined by the Resource Conservation and Recovery Act (RCRA), Subtitles C and D, respectively. Industrial solid wastes not defined as hazardous under Subtitle C fall under Subtitle D of RCRA. See U.S. Congress, Office of Technology Assessment, *Managing Industrial Solid Wastes From Manufacturing, Mining, Oil and Gas Production, and Utility Coal Combustion-Background Paper, OTA-BP-O-82* (Washington DC: U.S. Government Printing Office, February 1992), pp. 4-15.

[10] Up to 70 percent of the weight of industrial solid waste (which includes mining, oil and *gas,* and manufacturing wastes) consists of wastewater contained in sludges and aqueous solutions.

[11] As figure 2-3 indicates, industrial wastes *clearly* dwarf MSW by weight. In terms of environmental impact, even if all MSW were ''hazardous,'' industrial "hazardous" wastes alone would still be three times as large. Furthermore, some of the "non-hazardous" wastes do not differ substantially from wastes designated as "hazardous" under the Resource Conservation and Recovery Act, or they may exhibit other characteristics of concern (see *OTA, Managing Industrial Solid Wastes From Manufacturing, Mining, Oil and Gas Production, and Utility Coal Combustion-Background Paper,* op. cit., footnote *9,* p. 12).

[12] For example, the energy required to manufacture motor vehicle components and assemble those components into finished vehicles totaled about 1.5 quadrillion Btu (quads) in 1985. However, the fuel used in motor vehicles totaled more than 10 times that amount. Sources: 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), p*3;* U.S. Department of Energy, Energy Information Administration, *Annual Energy Review 1990,* DOE/EIA-0384(90) (Washington DC: U.S. Government Printing Office, May 1991), p. 53.

Figure 2-2—Municipal Solid Waste Management (1960-90)



The generation of municipal solid waste (MSW) roughly doubled in the last three decades, increasing from 88 million tons in 1960 to 196 million tons in 1990 (population growth accounts for roughly one-third of the increase). Techniques of managing MSW changed somewhat during this period: recycling and comporting increased substantially; total incineration remained roughly constant but nearly all incineration now occurs with energy recovery; landfilling increased for most of the period, but has leveled off in recent years.

SOURCE: Franklin Associates, Ltd., personal communication, August 1992.

blowing agents, which have been linked to depletion of the stratospheric ozone layer.

In some cases, the environmental releases from products can be larger than those from the associated industrial processes. For example, heavy metals (e.g., mercury, lead, cadmium, chromium, and nickel) are among the most toxic constituents of industrial wastes.[13] Although complete data on industrial inputs and outputs of heavy metals are scarce, data collected under New Jersey's Worker and Community Right to Know Act of 1983 indicate that most heavy metals that enter industrial processes end up in products, not industrial wastes. In 1990, for example, at least 55 to 99 percent of industrial inputs of these five heavy metals were used in products, depending on the metal.[14] While some of these products are recovered and recycled,[15] much of the heavy metal content of products is released into the environment (e.g., in paints and coatings) or enters landfills and incinerators (e.g., in plastics).

TRENDS IN MATERIALS USE

During this century, dramatic changes have occurred in the nature of the materials Americans use to manufacture products. Figure 2-4 shows the consumption of different classes of materials in the United States between 1900 and 1989.[16] The top half of the figure shows consumption in absolute terms. During the past 90 years, consumption of raw materials derived from agricultural and forestry commodities has grown slowly. In contrast, there has been dramatic growth in consumption of raw

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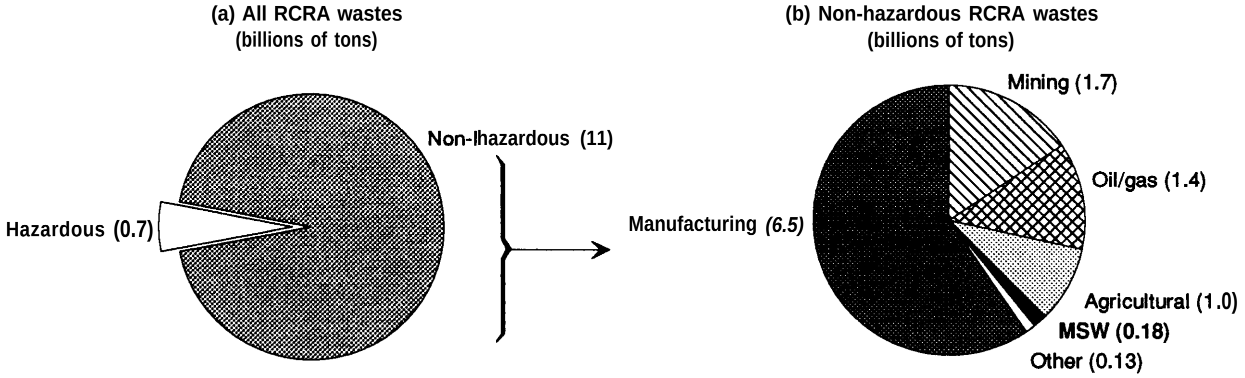
[13] These five heavy metals are all targeted in the Environmental Protection Agency's 33/50 Program—an effort aimed at encouraging industry to voluntarily reduce releases of 17 priority chemicals 33 percent by the end of 1992 and 50 percent by the end of 1995. See U.S. Environmental Protection Agency, Office of Pollution Prevention and Toxics, *Pollution Prevention Resources and Training Opportunities in 1992*, January 1992, pp. 84-85.

[14] Data from Andrew Opperman, New Jersey Department of Environmental Protection and Energy, Community Right to Know Program, Bureau of Hazardous Substances Information, personal communication, August 1992.

[15] Recycling rates vary substantially by material. For example, more than 50 percent of lead is recycled, *but* nearly all cadmium is released into the environment.

[16] Figures 2-4a and 2-4b measure material consumption by *value* to allow aggregation of diverse material types such as bales of cotton, barrels of oil, tons of ore, and cubic feet of gas. The figure only includes materials consumed for uses other than food and fuel. Source: David Berry, Program Manager, Material Use Trends and Patterns, Bureau of Mines, U.S. Department of the Interior, personal communication July 1992.

Figure 2-3-' 'Solid" Wastes as Defined Under the Resource Conservation and Recovery Act (RCRA)



Much of the solid waste produced in the United States is not directly generated by consumers. Municipal solid waste, the focus of much public concern, represents less than 2 percent of all solid waste regulated under RCRA. In contrast, industrial activities produce about 700 million tons of hazardous waste (a) and about 11 billion tons of non-hazardous wastes (b).

NOTE: All numbers are estimates. The non-hazardous waste total has been rounded to reflect uncertainty, Much of the "solid" waste defined under RCRA, perhaps as much as *70* percent, consists of wastewater. The terms hazardous and *non-hazardous* refer to statutory definitions of Subtitles C and D of RCRA, respectively. The mining wastes shown in (b) exclude mineral processing wastes; the oil/gas wastes in (b) exclude produced waters used for enhanced oil recovery; the "other' category in (b) includes wastes from utility coal combustion.

SOURCE: Adapted from U.S. Congress, Office of Technology Assessment, *Managing Industrial Solid Wastes From Manufacturing, Mining, Oil and Gas Production, and Utility Coal Combustion, OTA-BP-O-S2* (Washington, DC: U.S. Government printing Office, February 1992).

materials derived from ores and minerals (used in the production of steel, aluminum, and asbestos) and of raw materials derived from organic feedstocks (used in the production of plastics, fibers, petrochemicals, and asphalt).

The bottom half of figure 2-4 shows these shifts in comparative terms. In 1900, the majority of the raw materials consumed were derived from agricultural and forestry products. By the late 1980s, materials derived from ores and minerals constituted about 50 percent of all raw materials, up from only about 30 percent in 1900; materials derived from organic feedstocks (such as plastics, fibers, petrochemicals, and asphalt) comprised about 15 percent of the total, while in 1900 these materials practically did not exist.

A closer examination of these changes reveals three important trends in materials use: increasing variety, increasing efficiency, and increasing complexity. These trends are closely related, but each is significant in its own right.

Increasing Variety

Materials use has changed not only in terms of the relative amounts of different materials, but also in the variety of materials available. A century ago, U.S. industry utilized only about 20 elements of the periodic table; today, virtually all 92 naturally occurring elements are used.[17] Moreover, with advances in the understanding of the structure of physical matter, researchers have created thousands of chemical compounds and a broad array of novel materials. In chemicals alone, it is estimated that over 60,000 have been synthesized and roughly 10,000 are produced in commercial quantities.[18] About 1,000 new chemicals are introduced each year, and are incorporated into products as diverse as pharmaceuticals, superadhesives, and agricultural pesticides.[19]

Remarkable advances in structural materials technologies have led to the development of ceramics and composites that offer superior properties (e.g., high-temperature strength, high stiffness, and light weight) compared with traditional materials such as

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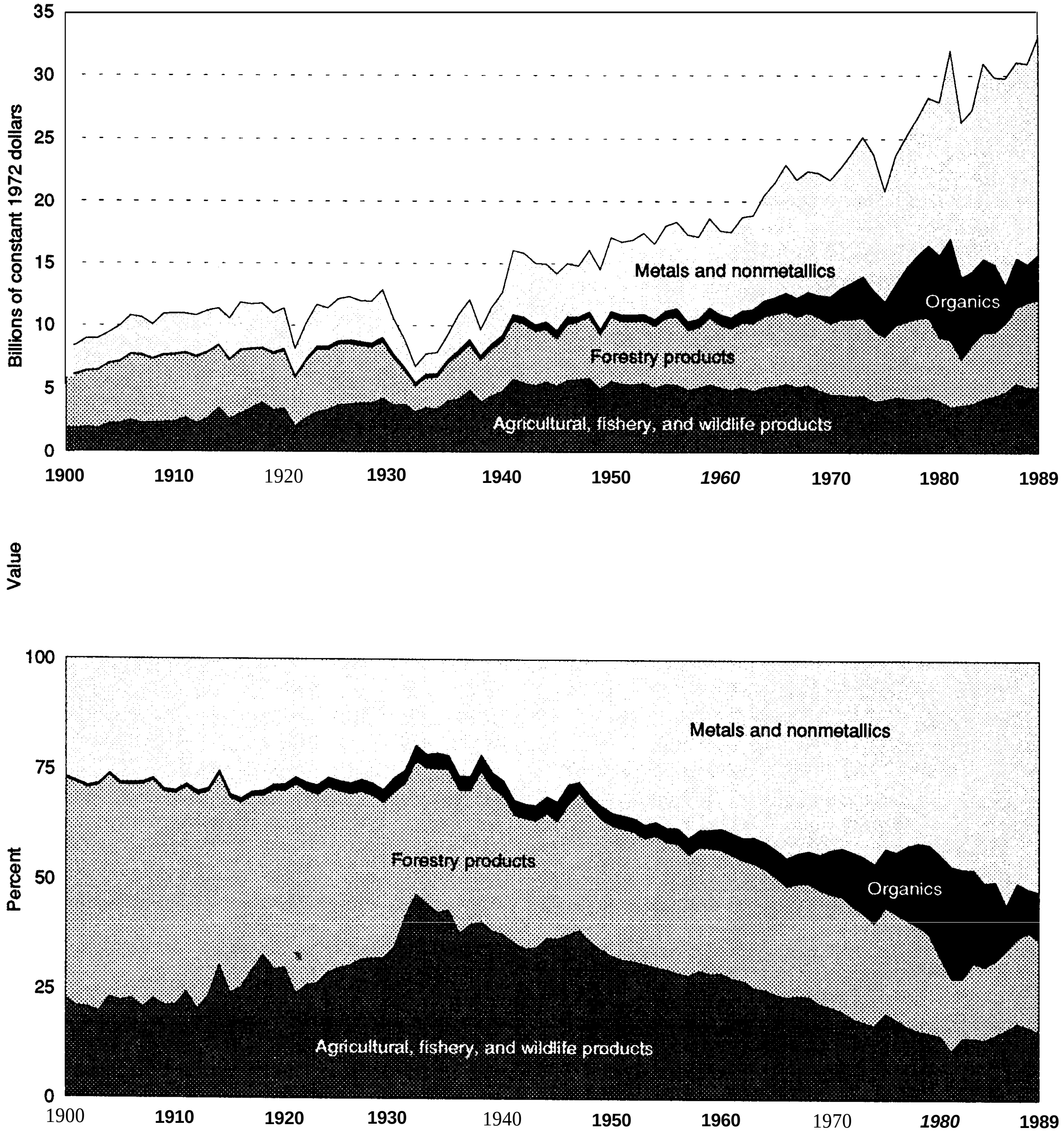
[17] *Materials and Man's Needs: The History, Scope, and Nature of Materials Science and Engineering,* vol. I. (Washington, DC: National Academy of Sciences, September 1975), ch. 1, p. 2.

[18] Michael Shapiro, "Toxic Substances Policy,'' *Public Policies for Environmental Protection,* Paul R. Portney (cd,) (Washington, DC: Resources for the Future, 1990), p. 195.

[19] Ibid.

Figure 2-4--U.S. Raw Material Consumption (1900-89)



U.S. raw material consumption has changed dramatically in this century. In absolute terms (top), raw material consumption has increased by a factor of 4 (population has increased by roughly a factor of 3 during the same period). The largest increases were in materials derived from mining operations (metals and nonmetallic ores) and from organics (plastics and petrochemicals). In relative terms (bottom), the sources of raw materials consumed in the United States have gone from predominantly agriculture and forestry to predominantly mining and organics.

NOTE: The data measure material consumption by value to allow for aggregation of diverse material types. The data oniyinclude materials consumed for uses other than food and fuel.

SOURCE: Data prior to 1978 from Vivian E. Spencer, *Raw Materials in the United States Economy,1900-1977* (Washington, DC: U.S. Department of Commerce, Bureau of the Census, 1980); data after 1978 from Bureau of Mines, op. cit., footnote 16.

steel and aluminum.[20] These materials can be engineered to have the precise properties required for a given application. Use of such designed materials can lead to higher fuel efficiency, lower assembly costs, and longer service life for many manufactured products.

Recent developments in materials technology are impressive in terms of both breadth and ingenuity. High-temperature superconductors offer the promise of extremely efficient electronic devices and power transmission systems.[21] Conductive plastics may someday combine the electrical characteristics of copper with the strength of steel, and may lead to lightweight batteries and electric motors.[22] ‘Smart’ materials-materials that sense and react to changes in their operating environment-may result in helicopter rotors that stiffen in response to turbulence or temperature fluctuations, or shock absorbers that automatically adjust to changing driving conditions. Molecular beam epitaxy techniques allow semiconductor devices to be built atom by atom, suggesting the possibility of hand-held supercomputers and ultra-small, low-power lasers for use in communications.[23]

Even the profound impacts of these so-called “engineered materials” may eventually be overshadowed by biologically derived substances. By harnessing the enzymes of nature, an entirely new range of nontoxic, renewable, biodegradable, and biocompatible materials may be on the horizon. Researchers are looking at how biopolymers might be used for applications as diverse as artificial skin, superabsorbants, dispersants, and as permeable coatings for agricultural seed. Several biologically derived polymers are already in production.[24] Ultimately, plants may be genetically programmed to produce plastic instead of starch.[25] Such developments could potentially reduce society’s dependence on petroleum-based materials.

Increasing Efficiency

New processing technologies, more sophisticated materials, and improved product design have resulted in the more efficient use of materials. For example, an office building that can be built with 35,000 tons of steel today required 100,000 tons 30 years ago.[26] similarly, aluminum cans today weigh 30 percent less than they did 20 years ago.[27][28]

Traditional materials have been displaced in many applications by new light-weight materials such as high strength alloys and plastics. For example, telecommunications cables in the 1950s consisted mostly of steel, lead, and copper, with a small percentage of aluminum and plastics (figure 2-5). By the 1980s, the plastics content of cables had increased to more than 35 percent and the lead content had dropped to less than 1 percent. If polyethylene had not replaced lead as cable sheathing, AT&T’s lead requirements might have approached a billion pounds annually.[29] The process of substitution continues: today, 2,000 pounds of

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[211] See U.S. Congress, Office of Technology *Assessment, Advanced Materials by Design,* OTA-E-351 (Washington, DC: U.S. Government Printing Office, June 1988).

[21] U.S. Congress, *mice* of Technology Assessment, *High-Temperature Superconductivity in Perspective, OTA-E-44(I* (Washington, DC: U.S. Government Printing Office, April 1990).

[22] ‘‘The Promise of *Conductive* Plastics,’’ *EPRI Journal*, July/August 1991, pp. 5-13.

[23] U.S. Congress, Office of Technology Assessment, *Miniaturization Technologies,* OTA-TCT-514 (Washington DC: U.S. Government Printing Office, November 1991).

[24] The chemical firm ICI is producing about 50 tons of polyhydroxybutyrate-valerate (PHBV) annually. See William D. Luzier, ‘‘Materials Derived From Biomass/Biodegradable Materials,’ *Proceedings of the National Academy of Sciences,* vol. 89, No. 3, Feb. 1, 1992, pp. 839-842.

[25] “*In* Search of the Plastic Potato,” *Science,* Sept. 15, 1989, pp. 1187-1189,

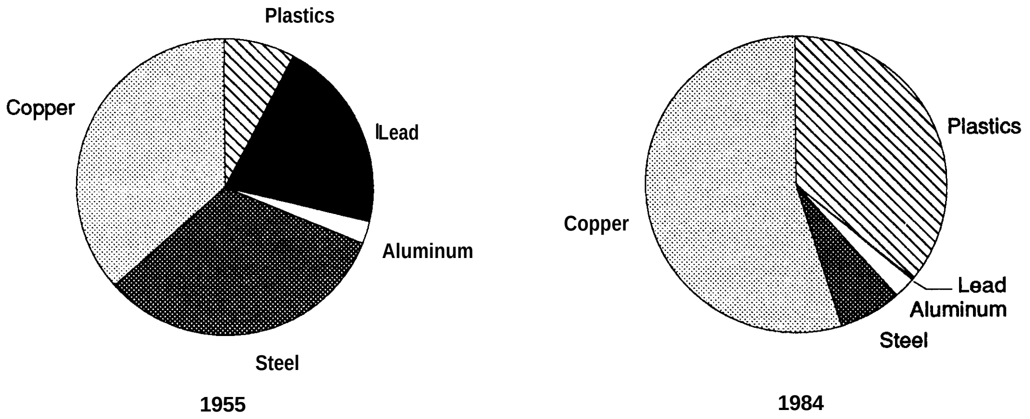
[26] Milton Deaner, President, American Iron & Steel Institute, presentation at the Bureau of Mines Forum on Materials Use, Washington, DC, Sept. 17, 1991.

[27] S. Donald Pitts, Vice President, Aluminum Association, presentation at the Bureau of Mines Forum on Materials Use, Washington, DC, Sept. 17, 1991.

[28] This increasing materials efficiency is a component of what some observers call ‘ ‘dematerialization”-a decrease in the materials consumed per unit of GNP. See Robert H. Williams, Eric D. Larson, and Marc H. Ross, “Materials, Affluence, and Industrial Energy Use,” *Annual Review of Energy* 12:99-144, *1987; Robert* Herman, Siamak A. Ardekani, and Jesse H. Ausubel, ‘‘Dematerialization,’’ *Technology and Environment* (Washington, DC: National Academy Press, 1989), pp. 50-69. Dematerialization offers the possibility that economic growth may not inevitably lead to more materials use.

[29] Jesse H. Ausubel, ‘‘Regularities in Technological Development: An Environmental View,’ *Technology and the Environment,* Jesse H. Ausubel and Hedy E. Sladovich (eds.) (Washington, DC: National Academy Press, 1989), pp. 70-91.

Figure 2-5—Materials Used for Manufacturing Telecommunications Cables by AT&T Technologies



The composition of telecommunications cables illustrates the changing use of materials. Polyethylene has replaced lead as the dominant material in the cables' sheathing. This shows how material substitution can reduce the use of materials with adverse environmental impacts.

SOURCE: P.L. Key and T.D. Schlabach, "Metals Demand in Telecommunications," *Materials* and *Society* 10(3):433-451, 1986.

copper can be replaced by 65 pounds of fiber-optic cable, with the production of fiber consuming only 5 percent of the energy required for copper.[30]

Increasing Complexity

Statistics concerning materials consumption do not capture a more subtle change with potentially important environmental consequences: a trend toward increasing complexity of materials use. As noted earlier, advances in chemistry, materials science, and joining technology have made it possible to combine materials in new ways (e.g., anticorrosion coatings on metals, or fiber-reinforced composites) to meet performance specifications more cheaply. This creates products that are more complex from a materials point of view.

As an illustration, consider the modern snack-chip bag depicted schematically in figure 2-6. The combination of extremely thin layers of several different materials produces a lightweight package that meets a variety of needs (e.g., preserving freshness, indicating tampering, and providing product information) .31 The use of so many materials effectively inhibits recycling. On the other hand, the package has waste prevention attributes; it is much lighter than an equivalent package made of a single material and provides a longer shelf life, resulting in less food waste.

Other products exhibit similar complexity. For example, automobiles are composed of a vast array of different materials, including high-strength steel, aluminum, copper, ceramics, metal-matrix composites, and more than 20 different types of plastic.[32] Even household laundry detergents contain many different components, each with a specific function: enzymes to dissolve biological stains, bleaches to whiten cleaned garments, and 'builders' to prevent dislodged dirt from resettling on fabrics.[33] The greater complexity of these products offers benefits to consumers, but this complexity also makes it more difficult to evaluate their environmental attributes.

Driving Factors

While these trends have important implications for future environmental policy, they are evolving independently of environmental considerations. Instead, they are driven by economic factors, by

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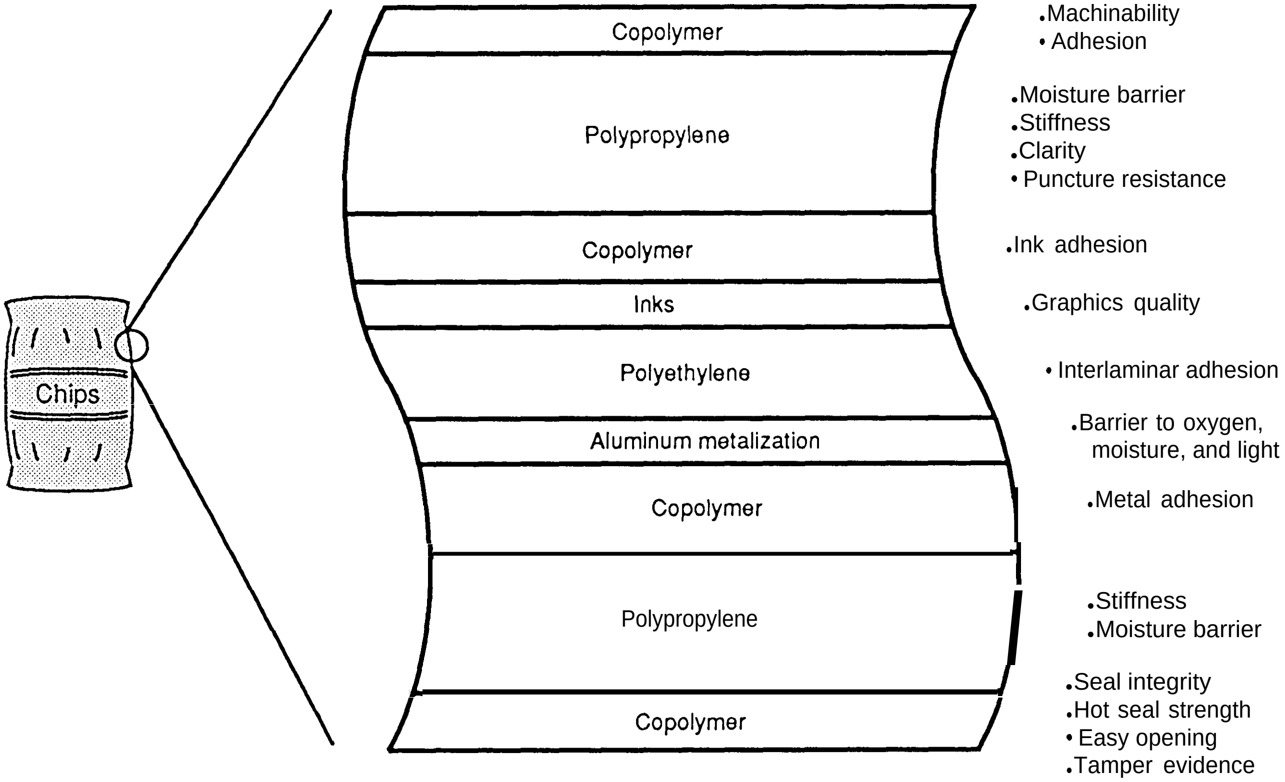
[30] U. Colombo, Proceedings of the Sixth *Convocation* of the Council of Academies of Engineering and Technological Sciences, pp. 26-27,1988, cited in Herman, Ardekani, and Ausubel, op. cit., footnote 28.

[31] Council on Plastics and packaging in the Environment, *COPPE Info Backgrounder*, "The Search for the Perfect Package: Packaging Design and Development,'' March 1992.

[32] Frank R. Field, *Materials Technology: Automobile Design and the Environment*, contractor report prepared for the Office of Technology Assessment, May 6, 1991.

[33] Andy Coghlan, "It May Be Green But Is It Clean?" New *Scientist*, May 4, 1991, p. 22.

Figure 2-6-Cross-Section of a Snack Chip Bag



This cross-section of a snack chip bag illustrates the complexity of modern packaging. The bag is approximately 0.002 inches thick, and consists of nine different layers, each with a specific function. While such complexity can inhibit recycling efforts, it also can reduce the overall weight of the bag, and keep food fresher, thus providing waste prevention benefits.

SOURCE: Council on Plastics and Packaging in the Environment.

advances in technology, and by competition to satisfy changing consumer needs. For example, high repair costs prompt many customers to buy new goods rather than repair old ones.[34] This has encouraged the design of more sophisticated, self-contained products (e.g., consumer electronics with batteries sealed inside) that are intended to be used and thrown away. The creation of nonrepairable, nonserviceable items has also been motivated by liability concerns relating to product safety .35 Meanwhile, improved manufacturing technologies have brought down the cost of such products, and more consumers can afford to purchase them, resulting in a greater number of goods that are discarded.[36]

The application of information technology to all stages of the production and marketing process has made shorter production runs affordable, enabling manufacturers to differentiate their product offerings and aim at narrower market niches. This has resulted in a proliferation of product lines (e.g., in automobiles, appliances, and computers). The increased ability to tailor products to individual needs comes at a time when changing lifestyles and a more diverse population are fueling demand for a wider

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[34] ChemCycle *Corporation Environmentally SoundProductDevelopment in the Consumer Electronics and Household Battery Industries*, contractor paper prepared for the Office of Technology Assessment July 1991.

[35] As goods have become more complex, the potential for consumer injury during repair has in many cases increased. It is not surprising then, that manufacturers are designing products so as to discourage consumer repair. Ibid.

[36] Ibid.

range of goods and services.[37] Elaborate production networks have been developed to meet the demands of these diverse markets (see chapter 4).

ENVIRONMENTAL POLICY IMPLICATIONS OF MATERIALS TRENDS

Are these trends good or bad for the environment? The answer is not always clear. Although complex products may be less recyclable, they may at the same time be more efficient in their use of energy and materials. For instance, advanced composite materials allow lighter components to be used in cars and aircraft, and consequently can lead to significant lifetime fuel savings and reduced air emissions. Multilayer food packaging can extend food shelf life. Steel-belted radial tires can be used year round, and are more durable than previous generations of tires.

With technologies available to create new materials and to combine conventional materials in new ways, designers are faced with more choices than ever before. Increasingly, these choices involve environmental dilemmas. Energy-efficient compact fluorescent bulbs, for example, contain mercury, a toxic heavy metal. In cases such as this, tradeoffs will be required, not only between traditional design objectives and environmental objectives, but among environmental objectives themselves: for example, waste prevention vs. recyclability, or energy efficiency vs. toxicity. In general, every design will have its own set of environmental pluses and minuses. This suggests several conclusions:

- The environmental evaluation of a product or design should not be based on a single attribute, such as recyclability; rather, some balancing of pluses and minuses will be required over its entire life cycle.
- The trend toward complexity seems certain to make the environmental evaluation of products more difficult and expensive in the future.
- Policies to encourage green design should be flexible enough to accommodate the rapid pace of technological change and a broad array of design choices and tradeoffs.

Looking Ahead

The pace of materials technology innovation continues to accelerate. As this chapter has shown, these innovations can lead to greater efficiency in materials use and less waste generated, measured per unit of production. This is an environmental triumph of a sort, since it means that environmental quality is greater than it would have been had these innovations not occurred. Policymakers should encourage these changes, but they must also recognize that what matters for future environmental quality is not just industrial efficiency, but the absolute quantity of resources used and wastes released to the environment. In absolute terms, more goods and services are being produced, and more wastes are being generated every year.

It is an open question whether present policies regarding economic growth can avoid irreversible environmental impacts or whether a drastic change is required. Conventional economic indicators do not address issues such as species loss and global climate change. To effectively face these challenges, measures of economic progress will have to be broadened to include not only industrial efficiency, but the overall health of human populations and ecosystems.[38] The next chapter explores how designers can begin to address these issues.

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[37] More women working outside the home and less leisure time translates into increased demand for convenience products such as single serving packages and microwaveable dinners. See U.S. Congress, Office 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), p. 22.

[38] There is a variety of ongoing work in this area. See Robert Repetto, "Accounting for Environmental Assets," *Scientific American,* June 1992, pp. 94-100.