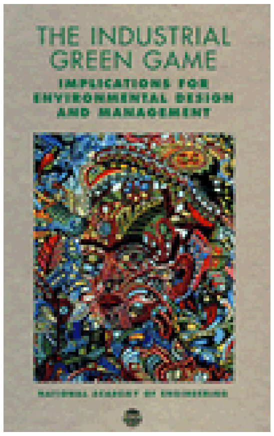

The Industrial Green Game: Implications for Environmental Design and Management

Deanna J. Richards, Editor, National Academy of Engineering

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THE INDUSTRIAL GREEN GAME

IMPLICATIONS FOR ENVIRONMENTAL DESIGN AND MANAGEMENT

Edited by
DEANNA J. RICHARDS

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Preface

The mainstreaming of environmental considerations in design and management decisions by companies as well as public-sector organizations is a relatively new phenomenon. The National Academy of Engineering (NAE), through its program on Technology and Environment has, since the late 1980s, taken a "best practices" approach to articulating emerging concepts that aid the mainstreaming process. This volume describes practices that are being used by a variety of industries in several industrialized countries to integrate environmental considerations in decision making.

Environmental issues facing corporations (and public agencies that regulate their actions) vary dramatically. How these issues are incorporated into decision making depends on the type of business; level and sophistication of corporate use of technology and information; employees' knowledge, management skills, and ingenuity; and the design and execution of a plan of action. Those firms that are farther along in making "green" products, using "clean" production, or delivering "green" services face difficult choices as they strive to improve environmental performance. But, as this volume suggests, learning and application of usable knowledge leads to continuous improvement.

The papers in this report were presented originally as part of an international conference on industrial ecology convened by the NAE in May 1994. Collectively, they describe concepts and present case studies and tools that contribute to the improvement of environmental quality.

Many individuals were involved in the preparation of this volume. On behalf of the National Academy of Engineering, I want to thank particularly the authors for their thoughtful contributions and the members of the conference steering committee—Peter R. Bridenbaugh, Robert Forney, Robert A. Frosch (chair-

man), Frank Joklik, Robert Laudise, Lee Thomas, and Kurt Yeager—for their help in organizing the conference.

I would also like to thank the NAE staff who worked on this project. Deanna Richards, who directs the NAE Technology and Environment Program, was primarily responsible for sheparding the project through its various stages. Peter Schulze, NAE J. Herbert Holloman Fellow, contributed valuable assistance along the way; Marion Ramsey, senior program assistant, provided critical administrative, logistical, and editorial support; Greg Pearson, the Academy's editor, contributed invaluable and steadfast editing and publishing oversight of this document. And Bruce Guile, former director of the NAE Program Office, gave advice and assistance throughout the project.

Finally, I would like to express my appreciation to the AT&T Foundation and the Ralph M. Parsons Foundation for their partial support of this project and to the Andrew W. Mellon Foundation for its partial support of related elements of the Academy's Technology and Environment Program.

WM. A. WULF
President
National Academy of Engineering

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The Industrial Green Game: Overview and Perspectives

DEANNA J. RICHARDS AND ROBERT A. FROSCH

The industrial green game involves the smart design of products, processes, systems, and organizations, and the implementation of smart management strategies that effectively harness technology and ideas to avoid environmental problems before they arise. The green game values environmental quality across the board in production and consumption activities and integrates environment as a strategic element in the design and management of economic enterprises.

The rules of the green game recognize that the entire system of production and consumption determines environmental quality. Environmental impacts are a function of the way services are provided and the way goods are produced, delivered, used, and disposed of. Production and consumption are considered together, because gains made by controlling, reducing, or minimizing pollution from production can be soon overshadowed by the impacts from concurrent increases in the scale of demand for those services and goods from a growing customer base.[1] Today, the scale of production and consumption is global. Advances in transportation and communication technology underlie a rapidly increasing internationalization of production and consumption. The regular flows of commerce—movements of people, raw materials, final goods, intermediate goods, and capital—cross national boundaries in enormous volumes on a daily basis. Indeed, we no longer live in small groups interacting with local ecosystems. Now, through the industrial support systems we have built and continue to evolve, we interact with the global environmental system as a whole. Yet, most recent environmental policy has focused on pollution from the point of view of industrial production.

At the same time, advances in areas like materials and production technologies are creating new types of companies. While the world has a long history of multinational companies, there is no precedent for the large and growing number of companies (or groups of companies) that now manage truly integrated global production systems and direct their products to an increasingly homogenous global market. In addition, the primary opportunities to reduce the adverse environmental impacts of economic activities continue to be technological. Conservation actions—such as reducing waste, or switching off lightbulbs—are important but among the simpler strategies one may adopt. Efficiency improvements—such as modernizing with more energy-efficient systems or re-engineering so that little or no waste is produced, or developing and deploying processes and systems that offer superior environmental quality—provide the greatest opportunity for improving environmental quality. These improvements often are driven by innovations in technology. Such advances, applied usually by private firms, are the means by which societies become less resource dependent and develop and deploy environmentally safer materials, processes, and systems. In this context, corporate decisions and the personal choices of consumers are important determinants of environmental quality.

The green game requires designing and manufacturing products (including facilities) and providing services by taking an environmental life cycle approach. This approach involves understanding and managing the environmental impacts of the material and energy inputs and outputs associated with the product or service from the extraction of the raw materials, through their many life stages (including reuse and recycle) to their reincarnation in new products or disposal.

The game calls for considering and managing the environmental impacts of the many activities that are reflected in the final costs of everyday goods and services. These activities include designing, developing, or making the product or creating the service; transporting, marketing, selling, maintaining or repairing the product; or even taking back the purchased product at or before the end of its useful life.

A systems approach is needed to play the game well. Industrial ecology[2] represents such an approach. In the noisy market of environmental terms and buzzwords, industrial ecology has become a short phrase for many ideas related to improving environmental quality with economic concerns in mind. Industrial ecology can be thought of in much the same way ecologists view ecology, as the study of the interactions among organisms and between organisms and their physical environment (Raven et al., 1995). Ecology is the study of processes and interactions, not a scientific prescription for solutions to environmental changes. Ecological study helps reveal how natural ecosystems operate, evolve, and are affected by the actions of humankind. Ecology provides the knowledge base that is then applied in a range of activities from forestry and agriculture to designing artificial wetlands and restoring the health of ecosystems. Similarly, industrial ecology views environmental quality in terms of the interactions among and between units of production and consumption and their economic and natural environments, and it does so with a special focus on materials flows and energy use. It also provides a strong basis for integrating environmental factors at various scales: the microlevel (industrial plant), the mesolevel (corporation or group or network of industrial activities that operate as a system for specific purposes), and the macrolevel (nation, region, world).

Industrial ecologists are interested in how industrial systems will evolve to meet environmental objectives. The industrial ecologist seeks to understand the current workings of industrial systems, how new technologies and policies may change the operation of those systems, and what impacts different industrial strategies may have on the economy and on environmental quality. This, then, forms a basis for wise decision making and good industry practices, driven by inquires such as those shown in Box 1.

This volume builds on earlier efforts of the National Academy of Engineering (NAE) in the area of technology and the environment.[3] It presents ideas for improving environmental quality through better design and management in industrial-related production and consumption activities. Concerns related to the impact of human-devised systems on the biosphere are addressed in *Engineering Within Ecological Constraints* (Schulze, 1996). The accompanying papers were presented at a 1994 NAE International Conference on Industrial Ecology. This overview draws on the papers as well as observations from two NAE workshops addressing the impact of the services sector on the environment, held in October 1994 and July 1995.

This overview first examines the changes to the playing field on which the green game is played. The rules of the game are defined foremost by a set of continually evolving regulations. Yet flexibility is needed to take advantage of new technologies, changing economics, and new modes of production that are in increasing use around the world. The green game has to be responsive to community concerns, including environmental justice. It has to respond to improved information and knowledge about environmental impacts, and their causes and potential solutions. All of this requires vigilance—to take advantage of opportunities for environmental improvement and to respond to unanticipated environmental consequences of technology and economic growth. It is ultimately driven by the costs of taking specific actions.

Next, the overview considers an old idea (Commoner, 1971) for managing materials: recycling. Many environmental impacts result from the accumulation in the biosphere of man-made and extracted raw materials. Therefore, materials management for the industrial green game can utilize systems that use waste as useful materials and substitute materials that improve environmental quality; systems for multiproduct cycles; and systems based on service or functionality.

The overview then looks at the information tools needed to guide environmental decision making within a corporation. A firm's green game is enhanced by understanding the environmental impacts inherent in the selection of materials and processes, by assessing associated environmental and health risks, and by improving the ability to track and assign responsibilities for environmental costs using effective performance measures. It is also critical to gain information about

BOX 1 Questions for the Industrial Ecologist

- How are production and consumption patterns changing, and how are these changes altering materials and energy flows within and among economic units?
- What are the impacts of the flows on natural systems and human health and how will these impacts change as new technologies are deployed?
- What data need to be collected to allow companies and governments to change the flows of potentially problematic materials through industries and economies?
- What are industry "best practices" to alter production systems and product designs to minimize environmental impact?
- How do new and existing technologies, economics, information, organizations, rules, and laws explain, control, or modify industrial operations and their impacts on human health and the environment?
- How will changes in technology, economics, information, organizations, rules, and laws meet environmental quality and econmic goals?
- What are new and different approaches to meeting those goals, and where are the opportunities to try them first?
- What are effective means of communicating complex risk and environmental impact information that is critical to everything from public policy to individual choices about products and services that may have different economic and environmental implications?
- What are usable and meaningful performance measures and indices for gauging progress toward meeting environmental quality and economic goals?
- What are the economics, time frames, and technologies associated with different scenarios of the future?

consumer attitudes toward the environment. This allows identified concerns to be managed, improves the reporting on a firm's environmental record, and is key for any environmental marketing a firm may do. Further, better knowledge of public understanding can be useful in communicating and managing environmental risks, and in responding to unanticipated environmental consequences of technology and economic growth, which are inevitable in the green game.

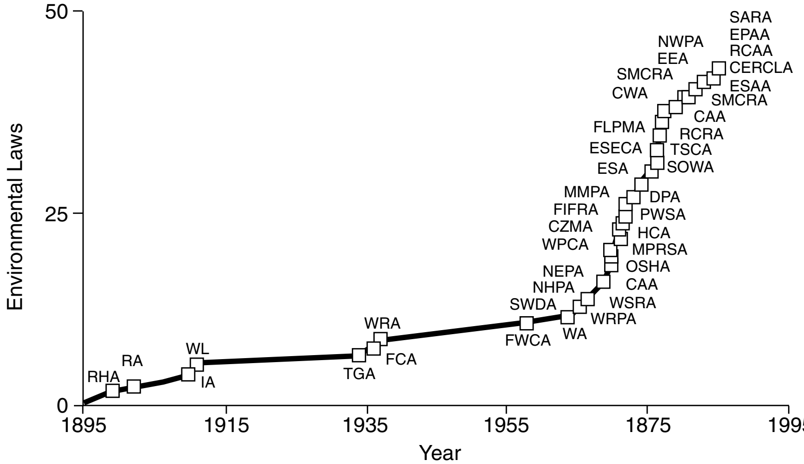
Finally, the overview examines tools that can provide clues for improving the way firms play the industrial green game. In this regard, there is an important government role in collecting and providing information that is unlikely to be gathered by private industry but which, if available, could have a large impact on improving the green game.

THE CHANGING PLAYING FIELD

The industrial green game is complicated by the fact that environmental costs are often not reflected directly in the value of products or services. If they were, products and services that impact the environment more than others would be priced accordingly. In practice, however, the cost of environmental damage is often incurred as the cost of protecting human health and the environment, and this expense is passed on essentially as overhead to the public. Subsidies further distort these costs by giving market preference to certain industries or practices.

The difficulty in determining environmental costs is illustrated by considering effluent charges. The notion of applying effluent charges is based on the seemingly logical rationale that polluters should pay for their actions. For example, a factory whose effluent impacts adversely fish populations imposes a cost on commercial fishermen without their consent. As long as the cost of the pollution is not incurred by the factory, it has no incentive to reduce the pollution. As long as factory ownership is unclear, the polluter has "free" access to the fishing hole for waste disposal. It is difficult, however, to determine the appropriate charge (or penalty) that will generate the "ideal" level of pollution, without knowing the costs of pollution damages. It is because this type of information is absent or difficult to determine that the industrial green game is so difficult to play. Some of the external costs of pollution have been internalized through environmental regulations, which often are designed to address single environmental concerns. Several U.S. regulations were enacted in response to crisis in various environmental media (for example, the Clean Water Act to address water pollution and the Clean Air Act to address air pollution) or to address specific pollution-management concerns (for instance, the Resource Conservation and Recovery Act to address solid waste management and the Comprehensive Emergency Response and Liability Act [also known as Superfund] to remediate contaminated land and groundwater).

In the United States, there is a 30-year record of "command and control" environmental regulation and enforcement that has dictated how companies addressed environmental, health, and safety issues. Businesses have responded to the regulatory "stick" by complying with regulations and applying technology to control pollution. The tangle of these regulations has grown extraordinarily rapidly (Figure 1). Sometimes, they thwart more systems-based approaches to improve environmental performance. Indeed, there is growing evidence that approaches other than those proscribed by regulations can effectively meet and sometimes exceed environmental standards or goals set by the regulation. One example is the joint U.S. Environmental Protection Agency (EPA)-Amoco study of opportunities to prevent pollution at an Amoco refinery. The results of the effort revealed that, compared to traditional steps to meet regulatory requirements, similar reductions in pollution could be achieved at lower cost ($11 million in-



1899 - River and Harbors Act (RHA)
1902 - Reclamation Act (RA)
1910 - Insecticide (IA)
1911 - Weeks (WL)
1934 - Taylor Graring Act (TGA)
1937 - Flood Control Act (FCA)
1937 - Wildlife Restoration Act (WRA)
1958 - Fish and Wildlife Coordination Act (FWCA)
1964 - Wilderness Act (WA)
1965 - Solid Waste Disposal act (SWDA)
1965 - Water Resources Planning Act (WRPA)
1966 - National Historic Prerservation Act (NHPA)
1968 - Wild and Scenic Rivers Act (WSRA)
1969 - National Environmental Policy Act (NEPA)
1970 - Clean Air Act (CAA)
1970 - Occupational Safety and health Act (OSHA)
1972 - Water Pollution Control act (WPCA)
1972 - Marine Protection, Research and Sanctuaries Act (MPRSA)
1972 - Coastal Zone Management Act (CZMA)
1972 - Home Control Act (HCA)
1972 - Federal Insecticide, Fungicide and Rodenticide Act (FIFRA)
1972 - Parks and Waterways Safety Act (PWSA)
1972 - Marine Mammal Protection Act (MMPA)
1973 - Endangered Species Act (ESA)
1974 - Deepwater Port Act (DPA)
1974 - Safe Drinking Water Act (SDWA)
1974 - Energy Supply and Environmental Coordination Act (ESECA)
1976 - Toxic Substances Control Act (TSCA)
1976 - Federal Land Policy and Management Act (FLPMA)
1976 - Resource Conservation and Recovery Act (RCRA)
1977 - Clean Air Acts Ammendent (CAAA)
1977 - Clean Water Act (CWA)
1977 - Surface Mining Control and Reclamation Act (SMCRA)
1977 - Soil and Water Resources Conservation Act (SWRCA)
1978 - Endangered Species Act Amendments (ESAA)
1978 - Environmental Education Act (EEA)
1980 - Comprehensive Environmental Response Compensation and Liability Act (CERCLA)
1982 - Nuclear Wasste Policy Act (NWPA)
1984 - Resource Conservation and Recovery Act Amendments (RCRAA)
1984 - Environmental Programs and Assistance Act (EPAA)
1986 - Safe Drinking Water Act Amemndments (SDWAA)
1986 - Superfund Amendments and Reorganization Act (SARA)

FIGURE 1 Growth in the Number of U.S. Environmental Laws. SOURCE: Balzhiser, 1989.

stead of $51 million) by taking approaches different than those required by the regulations (Schmitt et al., 1993; Solomon, 1993). The potentially stifling effect of regulation on innovation can be avoided by setting performance standards that companies may meet in whatever creative manner they devise.

More recently, incentives have been added to the "toolset" used to improve environmental quality. In a shift from its traditional enforcement programs, the

EPA has started to allow companies to take voluntary actions in partnership with the agency (U.S. Environmental Protection Agency, 1996). The agency has established compliance assistance centers to provide technical and other help to smaller companies that wish to comply with EPA requirements without provoking enforcement actions. Among the campaigns are several that provide support for and publicly recognize companies that reduce solid waste (Waste Wise), upgrade to more energy-efficient lighting (Green Lights), reduce release of certain high-priority chemicals (33/50), and introduce more energy-efficient products to the market (Energy Star).

Bans and taxes are nonregulatory, market-based tools that are used to reduce the environmental costs associated with materials. The ban on DDT is an example of a prohibition used to eliminate a harmful chemical. Taxes have also be used to phase out the use of chemicals. For example, when it became apparent that depletion of the ozone layer was linked to chlorofluorocarbons (CFCs), a graduated tax was levied on the substances and a target date was set for their phase-out. This sped the development and introduction of substitute chemicals and innovations that eliminated the need for CFCs in many applications.

Another more recent market-based innovation in the green game is the use of tradeable permits. Under this scheme, the environmental protection authority issues a limited number of permits allowing for the discharge of a specific amount of pollutants. The number of permits determines the quality of water or air. There is no guarantee that the initial number of permits is optimal, but the system ensures a given level of control by allowing permits to be traded. For example, in one current experiment, a manufacturer may increase sulfur dioxide emissions in locations where sulfur dioxide pollution is not a problem in exchange for reducing emissions in places where sulfur dioxide emissions do pose a problem. This leads to overall efficiency improvements. If a firm that has a permit is able to reduce pollution at less cost than are other firms, it can sell the right to pollute to a firm that is unable or unwilling to reduce its emissions. Under this scenario, the firm that sells the permits reduces its pollution level and still makes a profit from the sale of the permit.

In addition to regulation and market-based initiatives, environmental costs can be further internalized by efforts to encourage recycling or reuse. In the United States, the focus has been on recycling specific materials, such as paper, plastic, and certain metals, and requiring certain products to contain recycled material. In Japan, government policy and industry efforts have converged around the notion of a “recycle society” (Gotoh, this volume). In this society, well-designed technical and economic mechanisms would encourage industry and the public to seize every opportunity to recover, recycle, and reuse materials and energy to the maximum degree that is thermodynamically feasible and economically justified. To aid the creation of the recycle society, Japan has introduced recycling laws that cover a range of constituent materials and some finished products. They have also established an ecofactory research effort to develop technologies needed for environmentally conscious manufacturing (Japan External Trade Organization, 1993).

Germany has pursued a different tactic, requiring manufacturers to "take back" their products when they are discarded by the customer. Manufacturers are encouraged to recover useful material and energy and properly dispose of what is left. These initiatives make manufacturers responsible for the products they bring to market. The concept is often referred to as "product stewardship." Because regulations like these impact companies that compete globally, environmental concerns have become strategic. Companies have begun assessing the total environmental impacts of their products over the course of the product's full life cycle (Horkeby, this volume; Johnson, this volume; Marstander, this volume). They are also refining their financial analysis of products to identify in-house environmental costs, which previously were lumped into overhead (Ditz et al., 1995; Macve, this volume; Todd, 1994; Todd, 1997).

There are also other nonregulatory forces that are part of today's industrial green game. These include the emergence of voluntary international environmental standards (ISO 14000), citizen involvement, and environmental justice issues. These forces more fully explain the incentives corporations may have for evolving toward more socially oriented goals, such as environmental protection, as Allenby (this volume) speculates. Companies today can be found anywhere on the learning curve shown in Figure 2. Companies that *value* environmental quality—whether by force of regulation, because they see an economic opportunity in preventing pollution, or because they recognize the strategic importance of environmental factors or want to be "responsible" companies—are among those that are assessing the value of taking actions beyond basic compliance that will lead to less regulation, decreased liability, and better integration of environmental concerns with business practices.

SYSTEMS WHERE WASTE IS A USEFUL INPUT

Most environmental impacts result when materials accummulate in the biosphere. The materials may be naturally occurring and extracted from the earth, or they may be man-made. The management of materials is therefore critical to the industrial green game. One way to manage materials, which aims to avoid such accumulations, is to close the materials loop of production and consumption systems. Another is a no-growth approach based on an impractical premise of not extracting or creating the materials in the first place.[4]

The idea of closing the materials loop is not new. It derives from the observation that in natural systems, waste is a misnomer. Materials that are not used by a particular organism generally are used by others to grow and survive. This self-sustaining characteristic has evolved over time (Ayres, 1994), and, indeed, organisms that produce waste products do so without much thought about what happens to the waste. Until recently, the evolution of technological systems has

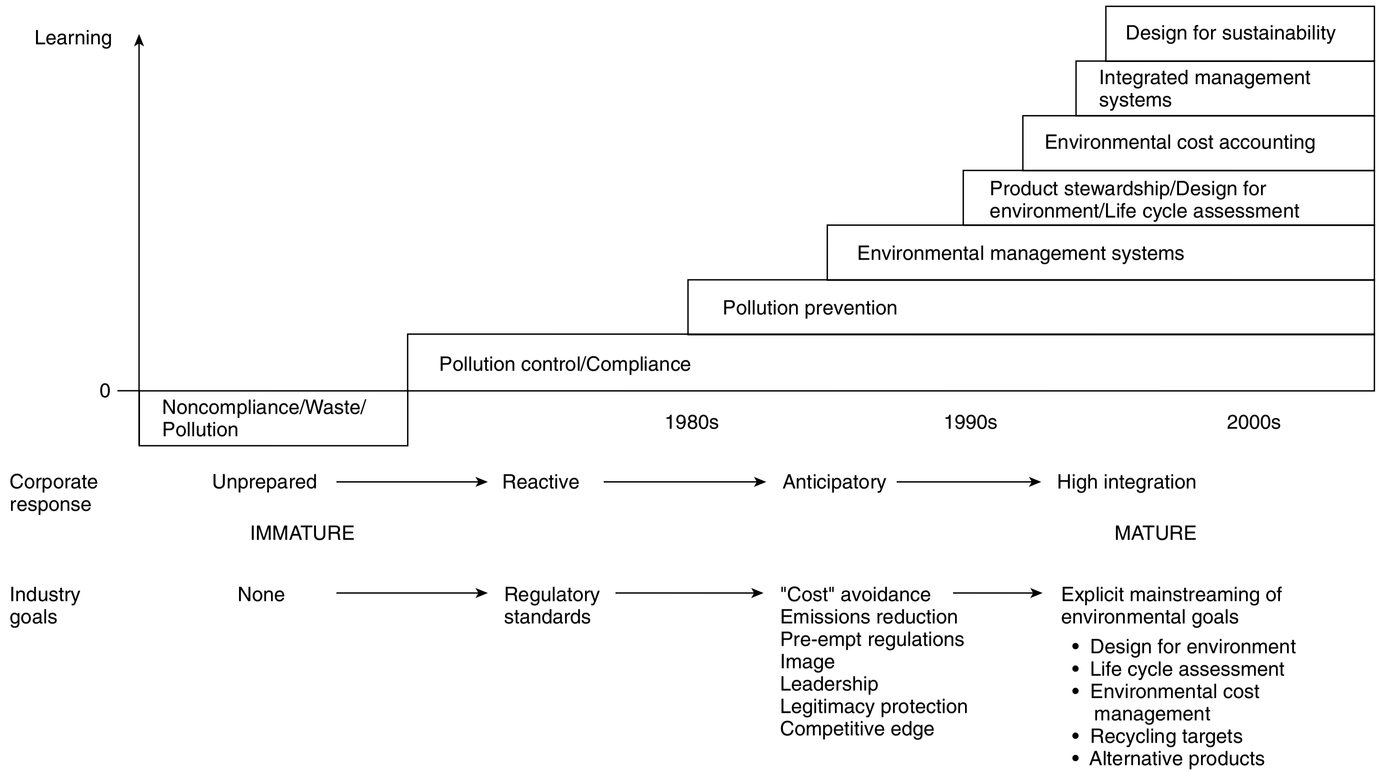


FIGURE 2 Industry's Environmental Design and Management Learning Curve. SOURCE: Adapted from Wever, 1995, and Ehrenfeld, 1995.

occurred with little thought about what occurs to materials that are "wasted" from the system. From a systems point of view, there is a danger in suboptimizing residual material from industrial processes or discarded products from consumer use. Frosch (this volume) warns that optimizing a particular process or subsystem to increase the efficient use of a material may be less effective than optimizing the system as a whole. Indeed, a larger, more complex, more diverse system may offer greater opportunity to efficiently use and reuse materials.

A example of the optimization that can occur at these larger scales is illustrated by the symbiotic workings of a set of industries in Kalundborg, Denmark (Grann, this volume). Here, a power plant, an oil refinery, a plaster-board manufacturing plant, a biotechnology plant, and a fish farm and surrounding farming community benefit from joint utilization of material residues that otherwise would end up as waste. In Kalundborg, refinery wastewater is used for power plant cooling; excess refinery gas and sulfur recovered by the refinery are used to manufacture plaster board; biological sludge from the pharmaceutical plant is used by farmers; steam from the power plant is used by the pharmaceutical plant; fly ash from the power plant is use by cement manufacturers in a different town; and waste heat from the power plant is used in fish farming and by the municipality as part of its heating distribution system.

The Kalundborg situation has been presented as an elegant model of what can happen when symbiotic relationships among industrial players are encouraged (National Science and Technology Council, 1995). This has spurred interest in communities to get co-located industries to examine the possibility of developing partnerships to improve use of residual material and to build eco-industrial parks.[5] These experiments will help the understanding of how materials flow at the local level and what needs to be done to better utilize them. However, there is a danger in viewing the Kalundborg model as the best way for industry to mimic nature with the goal of solving environmental problems. Most symbiotic relationships are not robust enough to handle changes in outputs such as would occur if a partner were to go out of business or find it more advantageous to not produce a waste in the first place. The small scale and limited diversity of such industrial ecosystems may make them fragile.

Another shortcoming of the Kalundborg model is that it presents too narrow a view of what is possible in terms of symbiotic relationships. There are other configurations that are worth considering. One involves looking at similar processes within an industrial sector. Figure 3, for example, shows the potential synergies among various material production plants, which may or may not be co-located.

Finally, the co-location model for creating symbiosis does not consider the changing nature of materials and their production, summarized in Table 1. Today's materials are more likely to be specialty, engineered, or advanced materials such as alloys, composites, laminates, or coatings than commodity materials. A potato-chip bag, for example, is not a simple paper or plastic product but a

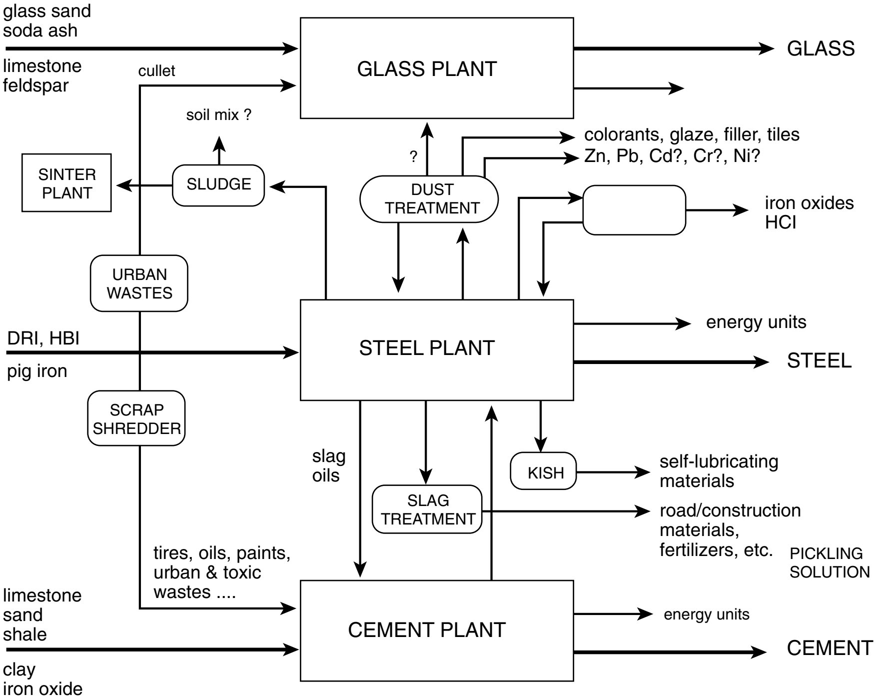


FIGURE 3 Potential synergies among various materials production plants. SOURCE: Szekeley, 1994.

complex material of several layers (Figure 4) that is more efficient than the packaging it replaced on a material weight per unit product basis. In fact, the trend in materials is toward complexity, variety, and efficiency (Eyring, 1994). These types of materials are drastically different from the simple materials (steam, sulfur, wastewater, sludge, and fly ash) that circulate in the Kalundborg model.

In addition, Table 1 shows that the newer materials are made not in plants dedicated to a single product, but in plants designed for flexible manufacturing where several different products may be produced, each with a very different waste stream. These plants, in turn, feed into an interdependent global economy, and their materials find their way into a diversity of products in a range of locations. This suggests a need for improved methods of assessing and managing risks associated with materials and processes used to make them. It also suggests the need for better separation technologies, if these materials are to be recovered and returned to commerce after they are discarded. Frosch (this volume) observes that even when recovery of useful material is technically feasible, it may be economically unsound, and when it is technical and economically satisfactory, a lack of information can still stymie implementation. Finally, when all else is

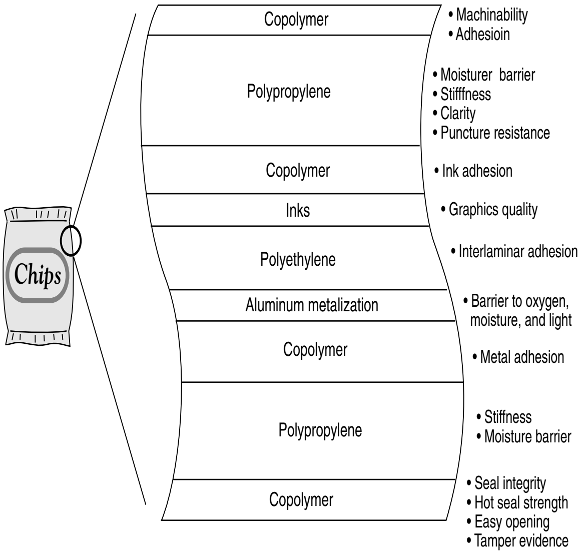


FIGURE 4 Cross-section of chip bag. SOURCE: U.S. Congress, Office of Technology Assessment, 1991.

satisfactory, there may be organizational problems, or the recovery effort can run counter to regulatory and legal requirements. What is needed is wise policy that removes barriers to improved movement of usable residual material and promotes the closing of materials loops at various scales.

DESIGNING SYSTEMS FOR MULTIPLE-PRODUCT CYCLES

The industrial green game requires that concerns about environmental quality include not only production and product use but also useful materials or potential energy embedded in products. In this strategy, products are used in several systems or product cycles, either as parts, materials, or embedded energy, as shown in Figure 5. Essentially, a product becomes input to several product cycles instead of merely finding its way to the trash heap after one life cycle. This simple idea, backed by regulatory pressures (e.g., German take-back legislation), has led some companies to innovate and use that innovation in marketing and advertising opportunities.

The utility of designing products for multiple product cycles depends on the product. Diversities in products and the manufacturing sectors that produce them (Table 2) have to be taken into account. An important distinction is the lifetimes of products. Some are made to function for a decade or more; others have lives

TABLE 1 The Evolving Materials Paradigm

Materials-As-Resource Paradigm	Value-Added Materials Paradigm
Resource-dependent materials	Information-, technology-dependent materials
Commodity materials	Specialty, engineered, advanced materials
Monolithic materials	Alloys, composites, laminates, coatings, ceramics
Structural materials	Functional material
Large-volume, continuous processes	Small-scale, batch processes
Plants dedicated to single product	Plants designed for flexible manufacturing
Price and availability as competitive basis	Quality, performance, service as competitive basis
Resource-oriented research	Manufacturing-oriented research
Environmental resources abundant	Environmental resources limited
Research performed by single principal investigators	Research performed by multidisciplinary,collaborative research teams
Self-sufficient economy, few potential vulnerabilities	Interdependent, global economy, many potential vulnerabilities
Metals dominance	Chemicals ascendance

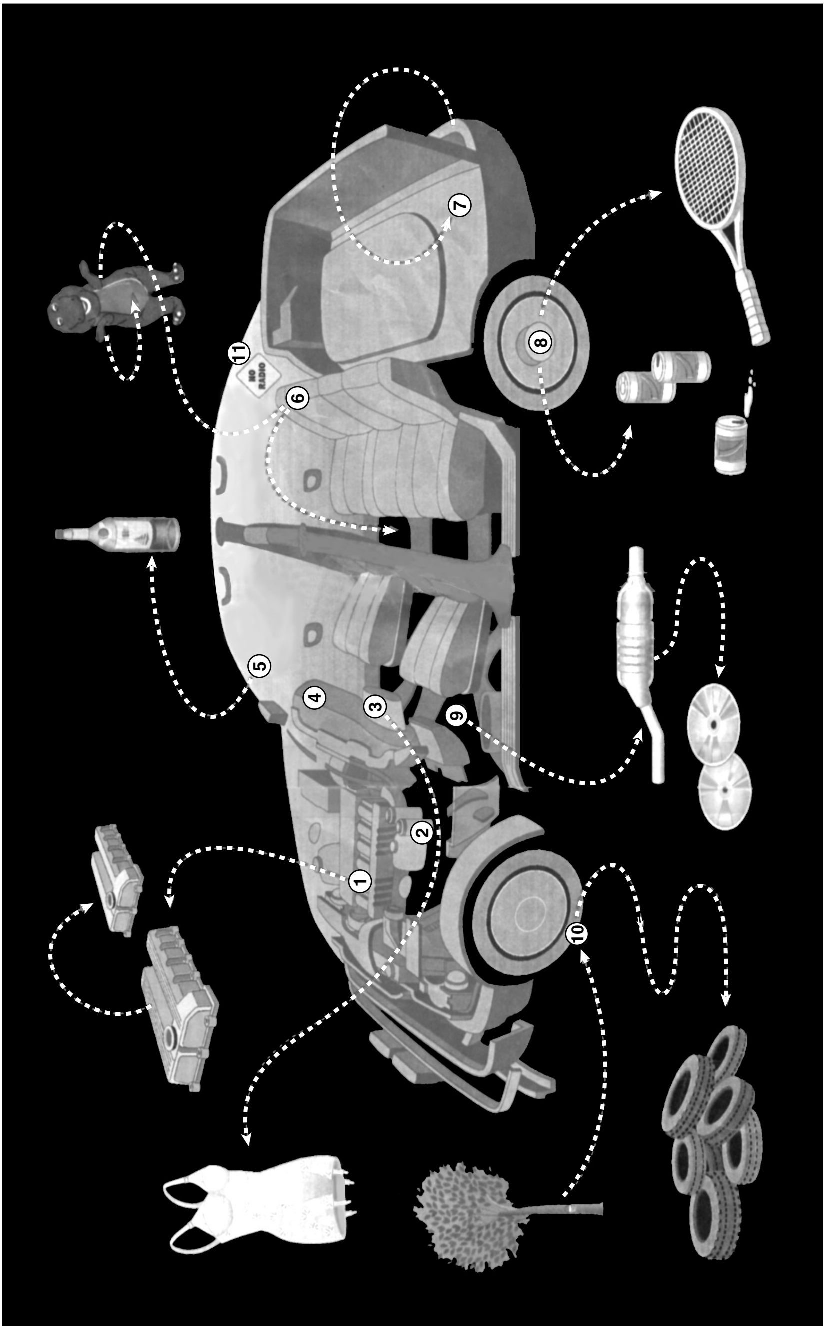
SOURCE: Sousa, 1992.

measured in months or weeks; still others are used only once. The designer and other's who bring a product into existence must adopt different design approaches to these different types of products according to their durability, materials composition, and recyclability (Graedel and Laudise, forthcoming).

As environmental objectives are introduced in product design, manufacturers are reexamining their approaches to a wide range of concerns, such as product and packaging design, materials selection, production processes selection, energy consumption, environmental market research, environmental labeling, and marketing. From a business perspective, the introduction of environmental objectives in product design must not cause delays in bringing the product to market. Green game strategies for managing the life-cycle impacts of products are summarized in Figure 6. These strategies are implemented in a variety of business processes: product design, production design, materials management, supplier chain management, order fulfillment, as well as service, maintenance, and asset recovery (Patton, 1994) (Figure 7).

Product Design

This is the method used by manufacturers to develop products to meet customer and market requirements. It begins with the definition of the product, a critical step that determines the features which will guide the product development team. This definition is reviewed throughout the product development cycle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(1) IS: Recycled plastic valve cover. (In most cars, valve covers are metal.) WAS: Plastic intake manifold (which draws air into the engine). MAY BE: Shredded and remolded into future plastic valve covers, perhaps eternally.

(2) ARE: Toxic fluids — coolants, various brake, engine and transmission lubricants. WERE: Usually destined to contaminate landfills. WILL BE: Drained immediately by salvager. Coolants can be resold; as for the rest — well, they're working on it.

(3) IS: Nylon air bag. WAS: Never used, fortunately. MAY BE: Women's underwear. Salvager must first deploy the bag to remove the toxic propellant. The nylon, which typically is shredded and discarded, then can be recycled and sold to various industries, automotive and otherwise.

(4) IS: Padded dashboard. WAS: Assembled from a multilayer amalgam of foam, metal and various plastics. WILL BE: Hard to recycle until someone devises a dashboard made of a uniform plastic that is both durable (safety always overrides recyclability) and aesthetically pleasing (i.e., not reminiscent of a 1972 Chevy Vega). Could be a long wait.

(5) IS: Windshield. WAS: In a large vat at the glass factory. MAY BE: A bottle of Scotch. (Increasingly, automotive glass is recycled by the container industry.)

(6) IS: Polyurethane seat filler and vinyl seat covers (in those rare cases, when the seats aren't covered with leather). WAS: Alas, nothing — at least not until engineers devise a non-cheesy-looking recycled polyurethane. MAY BE: Shredded and used as soundproofing in car floor, or sold to stuff Barney the dinosaur.

(7) IS: Luggage compartment liner made of recycled (not standard issue) polyurethane. WAS: Polyurethane bumper. MAY BE: Virtually any other part made chiefly of polyurethane. PROBABLY WON'T BE: Another bumper. In general, exterior parts, degraded by exposure to the elements, are recycled into interior parts.

(8) IS: Aluminum wheel. WAS: A bauxite deposit in Arkansas. MAY BE: Shredded and remolded into future wheels; down the road, perhaps, sold to make Venetian blinds, lounge chairs, tennis rackets, staples, screws, Pabst cans.

(9) IS: Catalytic converter. MAY HAVE BEEN: Another catalytic converter. MAY BE: Yet another. BMW now buys back used catalytic converters and chemically extracts the platinum, rhodium and other precious metals from the cores. These can be used to make future converters — or perhaps, Pearl Jam's next platinum disc.

(10) IS: Left front tire. WAS: Rubber tree somewhere in Malaysia. MAY BE: Shredded, sold and mixed with asphalt to make pavement. But more likely, tossed on a New Jersey waste dump, there to remain for the next millennium.

(11) IS: "No Radio" placard. WAS: Recycled paper pulp. WILL BE: Ignored, in all likelihood.

FIGURE 5 The ultimate used car. SOURCE: Jerome, 1993. Figure by Jaegerman. Copyright © 1993 by The New York Times Company. Reprinted with permission.

TABLE 2 Manufacturing Sectors and Their Products

Manufacturing Sector	Product Examples	Product Lifetime
Electronics	Computers, cordless telephones, video cameras, television sets, portable sound systems	Long
Vehicles	Automobiles, aircraft, earth movers, snow blowers	Long
Consumer durable goods	Refrigerators, washing machines, furniture, furnaces, water heaters, air conditioners, carpets	Long
Industrial durable goods	Machine tools, motors, fans, air conditioners, conveyer belts, packaging equipment	Long
Durable medical products	Hospital beds, MRI testing equipment, wheelchairs, washable garments	Long
Consumer nondurable goods	Pencils, batteries, costume jewelry, plastic storage containers, toys	Moderate
Clothing	Shoes, belts, polyester blouses, cotton pants	Moderate
Disposable medical products	Thermometers, blood donor equipment, medicines, nonwashable garments	Single use
Disposable consumer products	Antifreeze, paper products, plastic bags, lubricants	Single use
Food products	Frozen dinners, canned fruit, soft drinks, dry cereal	Single use

SOURCE: Graedel and Laudise (forthcoming).

to make sure that customer requirements are met without undue delays or increased costs on the final product.[6] Industrial green game objectives become part of the hierarchy of product requirements, related to such things as manufacturability, reliability, and safety that product designers must meet. The ongoing reviews offer additional opportunities to ensure that important environmental factors are not omitted as the product is developed.

The basic platform that emerges in the design process defines the initial product and its potential modifications. Products designed for easy upgrade, motivated by business opportunities for using the same platform for several products, offer substantial opportunities to reduce solid waste. This is because only some parts need to be redesigned to get the performance of a newer model. Designs that facilitate the exchange of circuit boards are examples of design for upgradability. A variation of this approach is the design of parts that may be used among several products lines or are interchangeable among different models. Design features such as these, together with product recovery and remanufacture, can result in a reduced solid waste load.

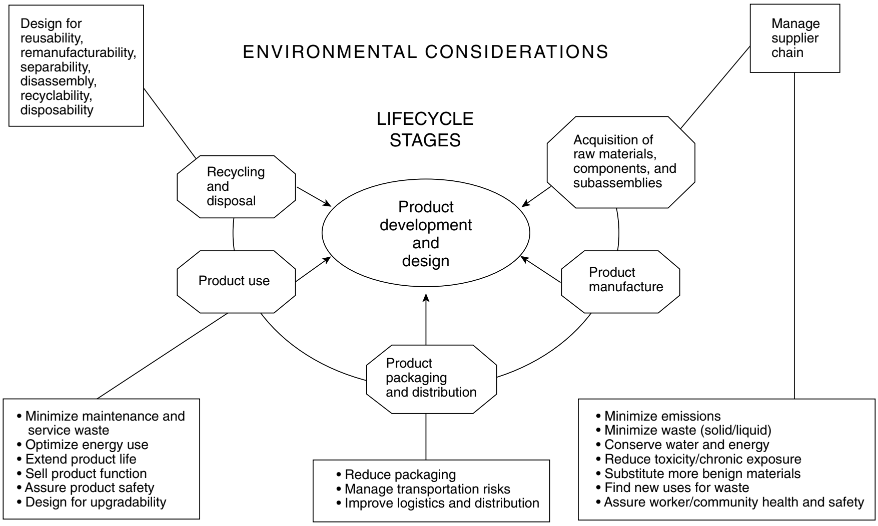


FIGURE 6 Product life cycle design. SOURCE: Richards and Frosch, 1994.

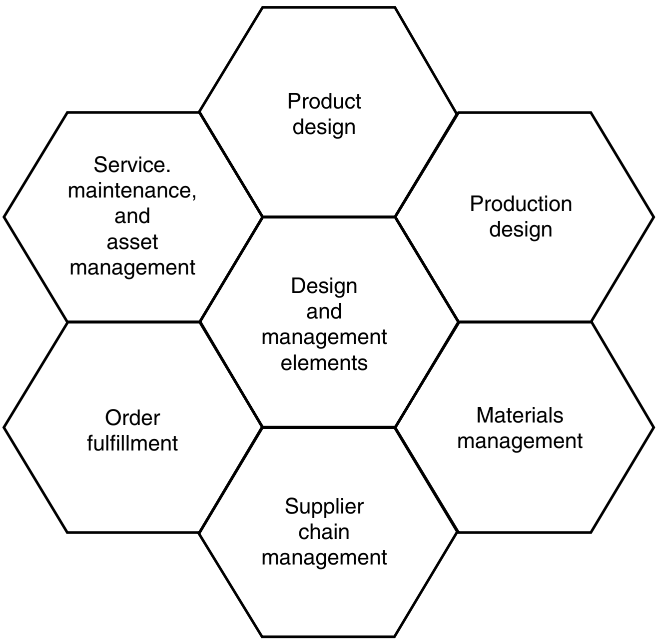


FIGURE 7 Business processes involved in managing the life cycle impacts of products.

Other more direct green game objectives that should be considered in product design include using less material or more energy-efficient components. Reduced use of materials translates easily to cost savings—smaller quantities of the material have to be purchased, less energy is used in its manufacture, transportation costs related to both the input materials and finished product are lowered, and there is less material to handle when the product is returned for disposal. Similarly, attention to the fate of a product, in terms of reuse or recycling, can result in product innovation. Reuse strategies that lead to reduced material costs can build brand loyalty among customers, who may be more likely to engage in repeat purchases from the original manufacturer, and provide source material to meet recycled-content requirements.

Production Design

Often the most effective strategy for improving environmental quality is to use the latest production technologies and processes. More advanced technologies tend to be more efficient and can be cleaner. Chiaro (this volume) describes the environmental advantages of new smelting facilities that use more advanced technology compared with those used by older smelting facilities. The selection of a new process technology or new equipment is often the result of tradeoff among costs, effectiveness, and environmental impacts. The environmental quality of the new technology can be assessed by carefully screening chemicals used in the processes and those that are emitted during production. In many cases, equipment can be bought from a wide selection of vendors who compete on a variety of factors, including cost and environmental quality. Tradeoffs between environmental objectives and other business goals can be gauged by assessing competing vendor bids against environmental criteria.

Materials Management

Materials management is one of the most important aspects of managing for environmental quality. Materials selection, chemical-use evaluation, and life cycle assessments are important ways in which materials management can be improved.

Materials are generally selected because they meet certain product form and function criteria (such as strength and durability) as well as production concerns (such as manufacturability). Reuse and recyclability are increasing concerns in materials selection, and there are several examples of how materials that facilitate reuse and recycling can result in green game gains by improving environmental quality and reducing cost. In the United States, where a strong secondary market exists for refurbishable auto parts and recycled auto materials, the economic value of more than 75 percent (by weight) of a car is recovered and reused. In electronics, a high-volume industry, reusable circuit boards are being channeled to service and repair operations (Holusha, 1996). The expense and initial difficulties of recycling plastic enclosures and other parts of electronic products have been addressed by simple strategies, like minimizing the diversity of plastics used and by clearly marking plastics in terms of several classifications of the material. When materials are carefully selected with reuse and recycling in mind, it is easier to create cost-effective (and sometimes profitable) relationships with recyclers and material vendors, to whom businesses might sell recovered materials. Such practices can also be useful in meeting government procurement requirements, which in many areas mandate the percentages of recycled materials that products should contain.

Chemical-use evaluations can be important in assuring that hazardous materials are not used in products and in identifying potential chemical-related problems early enough in design so that the product and process used for manufacture can be reengineered. Simple tools, such as checklists, can be effective in evaluating many materials. Recently, more systematic approaches such as life cycle assessments (LCA) are being used to guide materials use decisions.

LCAs are intended to evaluate the environmental impacts of products at every stage, from raw material extraction and production through distribution and disposal. They generally consist of three distinct but interrelated components:

- Life cycle inventory, an input-output accounting that quantifies the inputs of energy and raw materials and outputs of products, air emissions, water borne effluent, solid waste, and other environmental releases associated with the entire life cycle of the product, process, or activity.
- Life cycle impact analysis, a characterization of the effects of the environmental loadings identified in the life cycle inventory and an assessment of the loadings in terms of ecological and human health impacts.
- Life cycle improvement analysis, a systematic evaluation of the needs and opportunities to reduce the environmental burden associated with impacts of the inputs and outputs that have been inventoried and analyzed.

There are problems with LCA (Johnson, this volume). LCA is methodologically and analytically complex; creates the false impression that it includes everything; is data- and resource-intensive; neglects qualitative and unquantifiable factors; and frequently uses inadequate "surrogates" for environmental impacts. Furthermore, LCA has the potential for "paralysis by analysis," if the boundaries of the analysis are not well defined. In evaluating two products, it is reasonable to examine the raw materials used to make them. But, should the energy used to make the machinery used to extract the raw materials be included as well? Should the type, age, and efficiency of the machinery used to make the product be considered? And should the source of electricity be tracked back to it fossil, hydro, gas, or solar origins? LCA also is of little help for assessing the realistic impacts of pollution that often depend on time and location of occurrence. For example, a product ending up in well-run landfill will do less environmental harm than one that is not properly disposed. How should different types of environment impacts be compared and characterized? Life cycle assessment provides no answers to these questions. The challenge is in selecting boundary conditions that make sense, clearly identifying what those boundaries are, and then communicating the results of the analysis in a sensible manner.

One striking outcome of LCA and other similar models is what they reveal about the systems being assessed. Johnson (this volume) shows how LCAs of paper (as a product) reveal the complexity of the materials and energy flows of this simple material that is also 35 distinct products. In addition, simply cataloging and revealing the volumes of releases has proved effective in prompting reductions in waste. The prime example is the U.S. Toxics Release Inventory (TRI), which was created in response to the Emergency Planning and Community Right to Know Act of 1986. Under the law, companies are required merely to report their releases of waste, but even this simple step spurred actions to reduce waste and to understand the relative effects of various chemicals.

At a minimum, inventorying materials and energy flows can establish baseline information on a system's overall resource requirements, energy consumption, and emission loadings, and it can help identify opportunities for the greatest green game improvements in environmental quality. More sophisticated systems, such as Volvo's Environmental Priority Strategies System (Horkeby, this volume), can compare system inputs and outputs in assessing the environmental quality of comparable but alterative products, processes, or activities. This, in turn, helps guide the development of environmentally superior of innovations.

Most companies using some variation of life cycle assessments do so to verify claims they make in green advertising; to fend off unwanted regulatory pressures; and to identify opportunities to reduce the pollution impacts of their products and production processes.

Supplier Chain Management

Manufacturing today occurs though complex supplier chains. Often materials, parts, and components are made by different suppliers. At one extreme, the whole manufacturing effort is outsourced to suppliers. These "virtual manufacturers" provide the knowledge behind the innovation and then market products that are made entirely through supplier chains. All manufacturers rely to some degree on supplier chains, and their competitiveness depends on managing the supplier chain well. Technology partnerships, reuse or recycling relationships, and supplier evaluation have all been used to manage supplier chains for environmental quality.

Technology partnerships can involve a parent manufacturing company developing a technology for use by suppliers on a proprietary or fee basis. When electronics companies phased out the use of ozone-depleting chlorofluorocarbons as solvents to clean electronic circuit boards, the alternative water-based systems were developed primarily by the major manufacturers and shared with their suppliers (International Cooperative for Environmental Leadership, 1996). Plastics manufacturers, who are often part of several supplier chains, recognize that their competitiveness may well depend on their ability to create materials that can be recycled conveniently and cost-effectively. These manufacturers have developed and continue to engineer plastic resins to meet new requirements, eliminating ingredients that inhibit cost-effective recycling and establishing business relationships that will lead to the cost-effective recovery of resins in order to meet recycled-content requirements.

The importance of evaluating the environmental quality of supplier chains is critical to playing the industrial green game well, partly because of transnational differences in standards and practices. Suppliers must comply with environmental regulations in the countries in which manufacturers' products are eventually sold. Suppliers practices also must conform with any voluntary labeling a company uses to designate its product as "green." Manufacturers, therefore, have to understand their suppliers' practices and, more generally, assure environmental quality from the supplier chain by using surveys, questionnaires, audits, and third-party certifications.

Grann (this volume) shows how similar concepts are used in the building of a pipeline through a sensitive ecological area. His paper describes the use of British Standard BS 7750—Specification for Environmental Management Systems—and a forerunner of the international environmental standards ISO 14001[7] to manage environmental aspects of the project. A detailed environmental protection plan for the pipeline project was prepared to ensure a high level of environmental performance and strict adherence to all regulations, permits, and requirements. The plan included a set of environmental documents that were used by contractors to state their commitment to environmental protection by identifying environmentally critical operations, prescribing appropriate environmental measures, and giving detailed work instructions for proper job execution, control, and verification.

Order Fulfillment

The way in which orders are fulfilled to complete sales and deliveries can have major green game implications, particularly in packaging, inventory management, and distribution logistics. The strategy for dealing with packaging is similar to that associated with the product: Use less material, use biodegradable material, and design packaging for reuse and recycle. The less tangible aspects of fulfilling orders and of inventory management and distribution require the use of logistical information. Just-in-time manufacturing practices—matching production to market demand to eliminate storage or surplus of product—reflect how forecasting systems and inventory management can minimize the manufacture and storage of unsold products. Poor forecasting and inventory management are not only a source of unnecessary cost to manufacturing firms, they also mask large, hidden sources of environment impacts. Products that are scrapped because of poor inventory controls are good neither for profits nor environmental quality. Improvements in inventory management can have positive impacts on both profits and environmental quality.

The logistics of distribution are also an important determinant of environmental quality, particularly in terms of the energy used for transportation. When a company controls the distribution of its products, it can make effective gains in environmental quality. Increasingly, distribution is also outsourced often to large distribution service providers. Distribution-related concerns about environmental quality are most evident in mail-order-type businesses. An order may be called into a toll-free number and relayed to a supplier, who then either manufacturers the product or packages it and gets the product to the customer by land, sea, or air through a transportation and distribution service provider, such as the U.S. Postal Service or private companies like United Parcel Service. The changing nature of production and distribution will likely raise difficult questions about such issues as location, transportation, and logistics, which impact both cost and environmental quality concerns.

Service, Maintenance, and Asset Recovery

The service and maintenance of a product (particularly a long-lived product) can result in environmental impacts that are easily overlooked. As product life cycles get shorter, many more durable products, such as printers and personal computers, typically function long after the manufacturer has stopped making them. As a result, supplying replacement parts can be expensive for the manufacturer. However, discarded products may be an excellent source for reusable and refurbishable components (Holusha, 1996). The large volume of products to be serviced, and the high profitability of doing so, can make maintenance and repair services a ready outlet for large volumes of discarded parts.

Both legal and market requirements are forcing many businesses to collect and recover their products, or assets. Whether or not recycling or disposing of packages and products is economical depends heavily on product design. As legal and market dictates change, many businesses are responding by developing recycling systems. For example, to recycle the electrophotographic cartridges used in laser printers and fax machines, Canon developed different approaches to meet the characteristics of its two major markets (Maki, 1994). In Europe, the company uses its network of dealers as collection points. In the United States, where there are diversified sales channels over a vast geographical area, Canon collects its cartridges from customers through a prepaid parcel service. As an added incentive, the company contributes $1 to an environmental group of the customer's choosing for each cartridge returned.

Costs associated with service, maintenance and asset recovery include the design and development of collection schemes and encouragement of consumer participation. Since product return/recycle requirements are likely to become much more widespread, green game strategies should include arrangements for addressing asset recovery, and requirements for recovering costs should be addressed in each product line.

DESIGNING FROM A FUNCTIONALITY BASIS

Concerns about environmental quality are commonly viewed in terms of the hardware associated with the production of the product. The product may be a consumer good (like an automobile, a personal computer, or refrigerator), or a service (such as construction of roads, airports, pipelines, power stations, telephone cables, or other infrastructure). Turning this view on its head, the green game views the design of systems according to the "software," or functionality, derived from the product. The product becomes the service derived from the hardware: pest control as opposed to pesticides; temperature control, heat, and light instead of electricity; refrigeration instead of refrigerators; computing and telecommunication instead of computers, satellites, and cellular phones.

Stahel (this volume) suggests an economy based on functionality to decelerate the flow of materials within the economy. The idea allows manufacturers and others to exert control over the product life cycle by encouraging the customer to buy the function the product provides instead of the product itself. This is not a new idea but one that expands on past practices such as the leasing of phones. The trick for business is to build in the ability to upgrade to better and more efficient products as advances in technology provide greater energy efficiency and pollute less. Stahel points to Xerox, which advertises itself as a document company, and the design innovations the company has adopted to manage, upgrade, and maintain its inventory of photocopying machines that are used in high-volume sectors of the economy. In this instance, the company is selling documentation, not its machines.

The green game strategy of providing functionality instead of hardware is not applicable to all products nor is it one that will meet the needs of all customers. One outcome of the economy's growing service sector may be increased demand for leased products, better maintenance, and better protection against liability in operating longer-lasting products. The service sector, which currently accounts for 75 percent of jobs and 75 percent of GDP in the United States, includes operations such as hospitals, hotels, restaurants, photocopying services, real estate management, transportation and distribution companies, retail outlets, entertainment parks, cinemas, rental car agencies, and airlines. These types of businesses use many different products, and the decisions they make about environmental quality are related to functionality. Such businesses are more likely to lease these products, and when they purchase equipment, they value good maintenance that extends the life of products. United Postal Service, for example, extends the life of its truck fleet by practicing predictive maintenance—replacing parts based on their predicted life times—using sophisticated information systems that keep track of every part in every piece of equipment (Nielsen, 1995).

In discussing electricity as an energy source, England and Cope (this volume) focus on the values, or services, that electricity consumers derive from the product. The focus on end-use draws attention to the aim of the entire system to provide heat, light, temperature control, and so on. The ultimate goal is energy efficiency. In contrast, the motivations of actors upstream from end-use is to generate the maximum number of kilowatt-hours, to mine the maximum amount of coal or uranium, or to extract the maximum amount of fuel. The functionality-based approach leads to thinking about the linkages in the system and is quite different than a systems view of electricity generation. Energy efficiency becomes a critical aspect of managing the system. Moving upstream, toward generation of electricity, this approach points to other strategies for using waste heat and material produced during electricity generation.

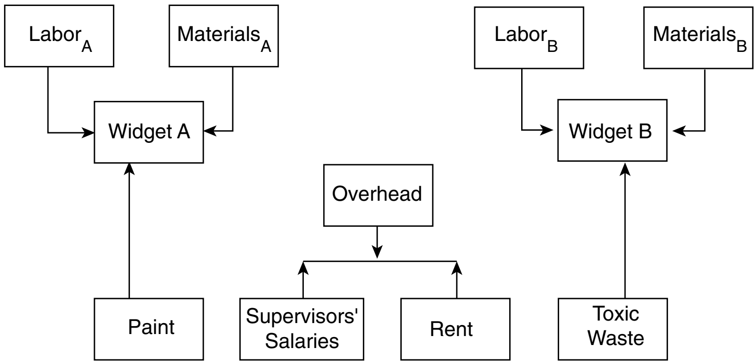
USING INFORMATION IN THE GREEN GAME

Information and its use are critical to the industrial green game, whether one talks about using waste as useful material, handling environmental considerations in the design stage, or designing systems on the basis of functionality. The discussion above covered a wide range of information uses, from simple inventorying to establishing a baseline of material and energy inputs, product outputs, and waste emissions; helping to select materials and evaluate the use of chemicals; providing details for managing the supplier chains; improving logistics and inventory controls; and facilitating maintenance in leasing operations for a functionality economy. There are three other areas where information aids the green game: accounting for environmental costs, measuring environmental performance, and gauging consumer attitudes about the environment.

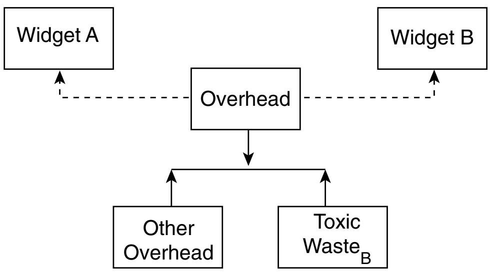
Accounting for Environmental Costs

Traditional accounting has often relegated environmental costs to overhead and hidden them from managers. A modified accounting scheme that gets at environmental costs is presented in Box 2. In this system, overhead is relegated to individual activities and responsibility is assigned to those with decision-making responsibilities. Macve (this volume) addresses the challenge of getting a better feel for overhead costs in multiactivity and multiproduct firms. He points out that activity-based accounting attempts to identify the causal relationships in an operation, regardless of how remote the links may be. He argues that from an economic and decision-making perspective, such allocations are basically arbitrary and irrelevant, since costs do not create value. What matters is how costs

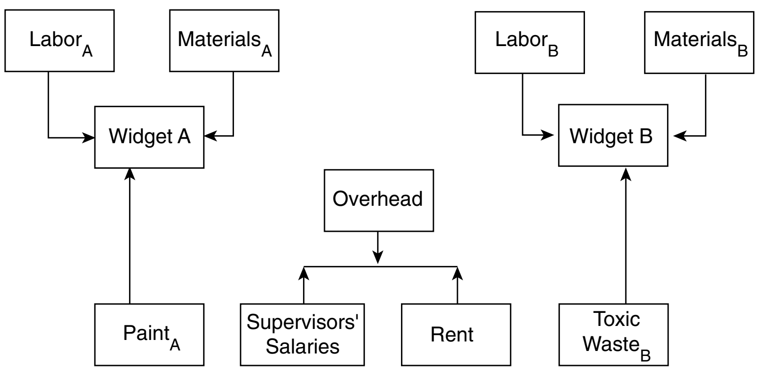
BOX 2 Traditional and "Enlightened" Cost Accounting



Traditional Cost Accounting (TCA)



Misallocation UnderTCA



Environmentally "Enlightened" Cost Accounting

SOURCE: Todd, 1994.

will change as a result of each decision—whether the extra revenue or other benefits the decision will bring are worth the extra costs. The accountant's approach is to develop systems of accountability and responsibility for costs and profits that provide norms and standards of human performance. The challenge of "environmental costing," Macve concludes, is not only to increase the technical sophistication by which environmental factors are tracked through to activities, but also to construct a new accountability that is linked to real incentives. As the field of accounting develops to provide better information about firms' environmental costs, it is likely to influence environmental-quality-related business decisions (Ditz et al., 1995) and improve the industrial green game.

Measuring Environmental Performance

The measurement of environmental performance is an effective tool when accounting for environmental costs is linked to incentives for managers to play the industrial green game well. What is measured is driven by policies a company may adopt, and a range of measures may be devised to gauge achievement against a set of objectives. The measures are most commonly absolute, such as achieving waste reduction of 200,000 tons against an objective of 150,000 tons. They also may be relative and time dependent, such as achieving an energy-use reduction of 20 percent compared with the previous year's result and against an objective of 30 percent for the current year. A combination of absolute, relative, and time-dependent measures are used to track four areas of environmental performance:

- Environmental Impacts. These are really measures of loading of materials and emissions that result in environmental impacts. They are useful in gauging the overall performance of a firm as well as for assessing the performance of individual organizational units, operations, or processes.
- Contributory Impacts. These relate to the performance of components of a firm such as plant and equipment, and materials quality and use, and to management systems such as training that contribute to the overall impacts.
- Risk Measures. These relate to the probability that the unexpected rare releases of a pollutant may result in potentially serious consequences. In such an instance, the risk, or probability, of such an event is a more useful measure of performance than the number of actual events.
- External Relations Measures. These relate to the environmental performance of the firm within the community. It includes everything from the number of complaints to the level of support of environmental programs.

In developing a system of measures for the green game, several factors should be considered (Business and the Environment and KPMG Peat Marwick, 1992).

First is the purpose of the measurement. If the goal is to understand impacts or to develop information for public reporting, it may be sufficient to measure and report on impacts. However, if the purpose is to guide management action to improve performance, then specific areas contributing to that performance and associated measures will have to be identified.

The second factor is the availability of information. Information that is readily available is more likely to be used. Much of the information can be gleaned through reviews or audits (Steelman et al., this volume) and then used to provide a basis for setting quantitative objectives against which performance may be measured.

Measurability is the third factor. In the industrial green game, simple measures such as energy efficiency or material-use efficiency are easier to determine than more complex factors such as supplier performance. Because continuous improvement is a feature of the green game, information should be gathered even if obtaining a measure is difficult and especially if a particular aspect of operation is considered important.

Finally, the controllability of what is being measured should be factored into the development of performance measures. Controllability and measurability are closely linked. Some areas of environmental impacts, such as emissions or energy use, are easier to measure and control. Others, such as supplier performance, customer satisfaction, or the environmental impacts of products, are more difficult to control but may be important to measuring performance.

Steelman et al. (this volume) and Marstander (this volume) provide details of how two companies gathered information to identify opportunities for continuous improvement. The essence of measuring performance in the industrial green game requires first identifying the information to be gathered. Progress is gauged by comparing these data with baseline information, and periodic audits are then used to evaluate progress in meeting environmental quality goals as well as identify areas for improvement.

Gauging Consumer Attitudes

As purchasers of products and services, consumers are critical to playing the industrial green game well. Consumer demand for "green" products and competition from companies that play the green game well determine the value companies place on meeting that demand. Simon and Woodell (this volume) track environmental policies as well as consumer attitudes toward the environment in Europe, Japan, and the United States. They use this approach as a basis for explaining the expectations of consumers for environmentally superior goods and services, the role customers expect of companies in addressing environmental concerns, the level of consumer involvement in environmental actions, the types and levels of environmental information sought by consumers, and the impacts of "green" advertising. Simon and Woodell find increasing confusion about what constitutes a truly green brand or company. They also find that, from a consumer's point of view, a product's environmental record ranks well below attributes such as price, quality, and past experience with the brand. However, environmental image is the only factor in brand choice, besides price, that has shown significant growth in the recent years. They also find a drop in the willingness of customers to pay a premium for environmentally preferable product. Several studies show a consistent pattern over time. In 1988, when asked if one would accept "a less good standard of living but with much less health risk," 84 percent agreed in the United States, 69 percent in Germany, and 64 percent in Japan. Two years later, in 1990, fewer accepted the same premise, with 65 percent of Americans, 59 percent of Germans, and only 31 percent of Japanese willing to sacrifice standard of living for a cleaner environment.

These trends present companies with the challenge of providing environmental quality as an added value to customers at little or no additional cost. Yet, there is growing evidence that simple waste reduction and energy-efficiency improvements can reduce costs, primarily by reducing the use of raw materials. Furthermore, environmental requirements that apply to products can have more complex financial and design trade-offs. But not making those trade-offs in good design and management can be more costly. For example, reuse or recycling can be very expensive for products that have not been designed with these requirements in mind. Collection and disassembly can be costly, and the resulting materials may have little or no recoverable value. On the one hand, products that are appropriately designed may be inexpensive to disassemble and may yield parts or materials with high recoverable value. In terms of revenue, products that are not designed with environmental requirements in mind can have disappointing sales for a variety of reasons, including that failure to address specific requirements may prevent their sale in a particular country or may preclude their consideration for specific bidding opportunities. On the other hand, products designed to meet environmental requirements may be able to increase company revenues by assuring worldwide acceptance or by taking market share away from competitors who are less able to respond to changing requirements.

Measuring Public Perception, Understanding, and Values

Understanding what the public knows and thinks about specific environmental issues is important in those instances where environmental improvements are forged through public debate, particularly when changing public policy or public behavior is necessary. Unlike surveys that are used to determine customer values, the "mental model" method (Morgan, this volume) can be used to get a better sense of what the public knows and thinks about a particular issue. The method gives participants no "clues" from which to form their responses, which is a problem with traditional surveys of public attitudes. Morgan argues that one gets a better understanding of the public's knowledge and thoughts on a particular subject using the more rigorous and time-consuming one-on-one interview process.

In many instances, industry actions intended to improve environmental performance can be taken without public debate or an assessment of the public's understanding of complex issues. That is not the case when it comes to communicating risk and developing policy to address industrial green game concerns such as global warming, health effects of electromagnetic radiation, or the use of genetic engineering in agriculture. The development of risk communication material that is based on an understanding of what the public knows and thinks will be important in managing a range of environmental and technology risk issues that are central to a winning green game strategy.

IMPROVING THE GAME

The industrial green game, executed primarily in firms, is played within larger physical, economic, and organizational systems and associated metasystems. Rejeski (this volume) characterizes the role of government as that of a navigator providing a broader and longer-range view than that of firms or individuals. He suggests three actions government can take to move the green game to a higher level of play and thereby improve the environmental performance of production and consumption activities.

- Mainstream environmental concerns into national accounts. This requires altering fundamentally the system of national accounts to get at the total environmental costs of the nation (and firm) by including natural capital and its depreciation and subtracting remediation costs and monetized environmental damages.
- Track and benchmark materials and energy use. This requires analyzing and continually improving environmental quality by mapping the metabolism of materials and the use of energy to provide policymakers with better contextual and historical snapshots against which national policies and alternative strategies may be assessed. It also requires benchmarking system efficiencies against "best-in-class" systems to identify potential improvements in the metabolism.
- Forecast technological change and set goals. This requires mapping potential outcomes of various technological trajectories on the economy and the environment and examining the trajectories for convergence with some set of long-range, socially defined and agreed-upon goals.

These suggested actions are not prescriptive or regulatory. They relate to developing important information that can be used in the policymaking and decision-making of firms in pursuit of environmental quality.

CONCLUDING REMARKS

As the green game is played out in corporate boardrooms, the shop floor, in the home, and in the community, it is clear that technology and engineering will continue to play a critical role in reducing many environmental impacts of production and consumption. Neither technology nor technological know-how are in short supply. The primary opportunities come from the continued, sustained application of existing technology to identified problems. The primary need is to create the incentives and techniques for companies to use technology and knowledge to improve environmental quality. The main barrier in this regard is the corporate manager, who sees dealing with environmental impacts only in terms of its costs or as a difficult trade-off between design and management.

The papers in this book suggest that a revolution is taking place in how private firms, across all economic sectors, are dealing with the environmental impact of production and consumption. It is not unlike the revolution that made safety and quality strategic concerns of most companies. In the next decade or two, the best and most profitable companies competing globally will understand the environmental impacts of their products (or service), production process (or service delivery), and operations. And, working with consumers or in response to market pressures, these companies will play the green game better, thus improving both their competitive position and the environmental quality of the planet.

NOTES

1. This statement is a reinterpretation in business terms of the simplified model of environmental impacts as being a function of population, rate of consumption (or affluence), and technological efficiency.
2. A recent review of industrial ecology (O'Rourke et al., 1996) provided a range of definitions for industrial ecology. There are several categories of industrial ecology. The first is the analogy of industrial ecology to natural systems: Traditional model of industrial activity—in which individual manufacturing processes take in raw materials and generate products to be sold plus waste to be disposed of—should be transformed into a more integrated model: an industrial ecosystem. In such a system the consumption of energy and materials is optimized, waste generation is minimized and the effluent of one process…serves as the raw material for another process (Frosch and Gallopoulos, 1989) based on the observation that

> In a biological ecosystem, some of the organisms use sunlight, water, and minerals to grow, while others consume the first, alive or dead, along with mineral and gases, and produce wastes of their own. These wastes are in turn food for other organisms, some of which may convert the wastes into the minerals used by the primary producers, and some of which consume each other in a complex network of processes in which everything produced is used by some organism for its own metabolism. Similarly, in the industrial ecosystem, each process and network of processes must be viewed as a dependent and interrelated part of a larger whole. The analogy between the industrial ecosystem concept and the biological ecosystem is not perfect, but much could be gained if the industrial system were to mimic the best features of the biological analogue. (Frosch and Gallopoulos, 1992).

The second relates to its application primarily to manufacturing, where industrial ecology has been defined variously as "…a new approach to the industrial design of products and processes and the implementation of sustainable manufacturing strategies" (Jelinski et al., 1992), as ". . . the totality or the pattern of relationships between various industrial activities, their products, and the environment" (Patel, 1992), as "designing industrial infrastructures as if they were a series of interlocking systems" (Tibbs, 1991), and "the network of all industrial processes as they may interact with each other and live off each other, not only in the economic sense but also in the sense of the direct use of each other's energy and material wastes" (Ausubel, 1992).

The third broadens the definition of industrial ecology to establish links to sustainable development and implies that

> Industrial ecology is the means by which humanity can deliberately and rationally approach and maintain a desirable carrying capacity, given continued economic, cultural, and technological evolution. The concept requires that an industrial system by viewed not in isolation from its surrounding systems, but in concert with them. It is a systems view in which one seeks to optimize the total materials cycle from virgin material, to finished material, to component, to product, to obsolete product, and to ultimate disposal. Factors to be optimized include resources, energy, and capital (Graedel and Allenby, 1995).

Finally, there is the non-normative definition that characterizes industrial ecology as "the complex mutual relations between human activities of industry and its surrounding environment" (Watanabe, 1993) or as "the study of the flows of material and energy in industrial activities, of the effects of these flows on the environment, and of the influences of economic, political, regulatory, and social factors on the flow, use, and transformation of resources" (White, 1994).

> All the definitions share one common concern: the integration of environmental considerations in decision making to reduce the environmental impacts of production and consumption.

3. Over the last several years, the National Academy of Engineering has, through its program on Technology and Environment, explored technology's impact on the environment through its role in production and consumption. Recent efforts in this area have focused on technology transfer (*Cross-Border Technology Transfer to Eliminate Ozone-Depleting Substance, 1992*); the relationship between science and environmental regulation and its effect on technological innovation (*Keeping Pace with Science and Engineering: Case Studies In Environmental Regulation, 1993*); industrial ecology and design for the environment (*The Greening of Industrial Ecosystems, 1994*); corporate environmental practice (*Corporate Environmental Practices: Climbing the Learning Curve, 1994*); The United State's and Japan's interest in industrial ecology (*Industrial Ecology: U.S/Japan Perspectives, 1994*); linkages between natural ecosystem conditions and engineering (*Engineering Within Ecological Constraints, 1996*); design and management of production and consumption systems for environmental quality (*The Industrial Green Game: Implications for Environmental Design and Management, 1997);* the diffusion patterns of environmentally critical technologies and their effect on the changing habitability of the planet (*Technological Trajectories and the Human Environment, 1997*); and the impact of services industries on the environment (exploratory workshops held in December 1994 and June 1995).
4. Most economic growth and environmental quality concerns relate to pollution intensity and depletion of natural resources. Some see growth as a threat to the carrying capacity of the planet—an argument that infuriates the developing world, which sees in such arguments attempts to limit growth. The growth/no-growth debate, however, is too narrowly defined. The

outcomes of any growth depend on the number of people to be supported by the growth, the types and kinds of economies and technology that make up the growth, the levels of material well-being, and the geophysical and biological environments in which growth occurs.

5. Four examples of the implementation of the eco-industrial park idea, in Baltimore, Md., Brownville, Tex., Port of Cape Charles, Va., and Chattanooga, Tenn., are discussed in the Eco-Efficiency Task Force Report (President's Council on Sustainable Development, 1996).

6. Product definition is not unique to manufacturing. Other terms may be used in industries such as mining, where the plan for exploration, extraction, through to final closure of the mine may be elements that are dealt with at the front end (Chiaro, this volume) in design, planning, construction, operation, and final restoration. The basic concept is to address existing and potential environmental quality concerns from the initial conceptualization of the product, facility, or service and to continually review and address potential concerns throughout development, operation, and retirement or end of product life.

7. The International Standards Organization (ISO) was chartered in 1946 to create harmonized, uniform world standards for the manufacturing, communication, and trade sectors in technical and safety matters. Since 1993, ISO has been developing ISO 14001, which establishes overall standards for organizational environmental management systems. It does not dictate performance, but lays out the essential elements and practices that organizations need to achieve regardless of external or internal environmental performance goals that are set.

   Other ISO 14000 standards that are being prepared cover environmental auditing, environmental performance evaluation, environmental labeling, life cycle assessment, and the environmental aspects of product standards. The product-based standards are likely to be the last in the series to be released, due to the lack of consensus on methodologies and approaches. They are however, likely to have the most far-reaching impact on business, since they are expected to demand data that are often difficult to generate and interpret.

REFERENCES

Ausubel, J. H. 1992. Industrial ecology: Reflections on a colloquium. Proceedings of the National Academy of Sciences 89:879–884.

Ayres, R. U. 1994. Industrial metabolism: Theory and policy. In The Greening of Industrial Ecosystems, B. R. Allenby and D. J. Richards, eds. Washington, D.C.: National Academy Press.

Balzhiser, R. E. 1989. Meeting the Near-Term Challenge for Power Plants. Pp. 95–113 in Technology and Environment, J. H. Ausubel and H. E. Sladovich, eds. Washington, D.C.: National Academy Press.

Business in the Environment and KPMG Peat Marwick. 1992. A measure of commitment: Guidelines for measuring environmental performance. London: Business in the Environment.

Commoner, B. 1971. The Closing Circle. New York: Bantam Books.

Ditz, D., J. Ranganathan, and R. D. Banks. 1995. Green Ledgers: Case Studies in Corporate Environmental Accounting. Washington, D.C.: World Resources Institute.

Ehrenfeld, J. 1995. Presentation at NAE Workshop on The Services Industry and the Environment, Woods Hole, Massachusetts.

Eyring, G. 1994. Trends in materials technology. Pp. 23–25 in Industrial Ecology: U.S./Japan Perspectives, D. J. Richards and A. B. Fullerton, eds. Washington, D.C.: National Academy Press.

Frosch, R. A., and N. E. Gallopoulos. 1989. Strategies for manufacturing. Scientific American 260:144-151.

Frosch, R. A., and N. E. Gallopoulos. 1992. Towards an industrial ecology. In The Treatment and Handling of Wastes, Bradshaw, et al., eds. London: Chapman and Hall.

Graedel, T. E., and B. R. Allenby. 1995. Industrial Ecology. New Jersey: Prentice Hall.

Graedel, T. E., and R. A. Laudise. (Forthcoming). Manufacturing. In The Ecology of Industry, D. Richards, ed. Washington, D.C.: National Academy of Engineering.

Holusha, J. 1996. Where old computer parts are given new lives. New York Times. June 10, D, 5:1.

International Cooperative for Environmental Leadership (ICEL) 1996. The International Cooperative for Ozone Layer Protection 1990–1995. Washington, D.C.: ICEL.

Japan External Trade Organization (JETRO). 1993. Ecofactory: Concept and R&D themes. Insert in New Technology Japan, February 1993. Tokyo: JETRO.

Jelinski, L. W., T. E. Graedel, R. A. Laudise, D. W. McCall, and C. K. N. Patel. 1992. Industrial ecology: Concepts and approaches. Proceedings of the National Academy of Sciences, 89:793–797.

Jerome, R. 1993. The ultimate used car. New York Times Magazine. October 31.

Maki, I. 1994. Canon's recycling initiative. Pp. 41–42 in Industrial Ecology: U.S./Japan Perspectives, D. J. Richards and A. B. Fullerton, eds. Washington, D.C.: National Academy Press.

National Science and Technology Council. 1995. Bridge to a Sustainable Future: National Environmental Technology Strategy. Washington, D.C.: National Science and Technology Council.

Nielsen, K. 1995. United Parcel Service (UPS) and Its Environmental Strategies. Paper presented at the National Academy of Engineering on the Service Industry and the Environment.

O'Rouke, D., Connelly, L., and C. P. Koshland. 1996. Industrial ecology: A critical review. International Journal on Environment and Pollution 6(2/3)89–112.

Patton, B. 1994. Design for environment: A management perspective. In Industrial Ecology and Global Change, Socolow et al., eds. Cambridge: Cambridge University Press.

Patel, C. K. N. 1992. Industrial ecology. Proceedings of the National Academy of Sciences 89:798–799.

The President's Council on Sustainable Development (PCSD). 1996. Eco-Efficiency Task Force Report. Washington, D.C.: PCSD.

Raven, P. H., L. R. Berg, and G. B. Johnson. 1995. Environment, 1995 Version. Saunders College Publishing.

Richards, D. J., and R. A. Frosch. 1994. Corporate Environmental Practices: Climbing the Learning Curve. Washington, D.C.: National Academy Press.

Schulze, P. (ed). 1996. Engineering Within Ecological Constraints. Washington, D.C.: National Academy Press.

Schmitt, R. E., H. Kleee Jr., D. Sparks, and M. Podar. 1993. Forming partnerships to protect the environment. Joint Amoco-EPA pollution prevention at the Yorktown Refinery. Paper presented at the NAE Workshop on Corporate Environmental Stewardship, August, Woods Hole, Mass.

Solomon, C. 1993. Clearing the air: What really pollutes? Wall Street Journal. March 29. A;1:1.

Sousa, L. J. 1992. Toward a new materials paradigm. Minerals Issues, (December). U.S. Department of the Interior, Bureau of Mines.

Szekeley, J. 1994. Personal communication.

Tibbs, H. B. C. 1991. Industrial Ecology: An Environmental Agenda for Industry. Boston: Arthur D. Little.

Todd, R. 1994. Zero-loss environmental accounting systems. Pp. 191–200 in The Greening of Industrial Ecosystems, B. R. Allenby and D. J. Richards, eds. Washington, D.C.: National Academy Press.

Todd, R. (Forthcoming). Environmental Measures: Developing an Environmental Decision-Support Structure. In Environmental Performance Measures and Ecosystem Condition, P. C. Schulze, ed. Washington, D.C.: National Academy Press.

U.S. Congress. Office of Technology Assessment (OTA). 1992. Green Products by Design. Washington, D.C.: U.S. Government Printing Office.

U.S. Environmental Protection Agency. 1996. Partnerships in Preventing Pollution: A Catalogue of the Agency's Partnership Programs. Washington, D.C.: U.S. Environmental Protection Agency. (Also available at http://www.epa.gov/partners.)

Watanabe, C. 1993. Energy and environmental technologies in sustainable development: A view from Japan. The Bridge 23(2):8–13.

Wever, G. 1995. Strategic Environmental Management Using TQEM and ISO 14000 for Competitive Advantage. John Wiley and Sons, Inc.: New York, NY

White, R. M. 1994. Preface. In The Greening of Industrial Ecosystems, B. R. Allenby and D. J. Richards, eds. Washington, D.C.: National Academy Press.

Concepts

The Industrial Green Game. 1997. Pp. 37–47.
Washington, DC: National Academy Press.

Closing the Loop on Waste Materials

ROBERT A. FROSCH

Throughout history, human economic activity has been characterized by an open and linear system of materials flows, where materials are taken in, transformed, used, and thrown out. Tools, clothing, and other products were forged and fashioned from natural plant, animal, and mineral materials. Worn-out goods and materials left over from the production process were often dumped in backyards. Archaeologists find discarded reminders of the past—scrap stone, flints, and potsherds—in the rubbish dumps of the Neolithic period. People moved to new habitats when the old locations became unsuitable because of accumulated wastes.

Today, there are more of us and fewer new places to which to move. We face serious pollution in many locations and and have poisoned some areas into uninhabitability. As human populations grow, discarding waste material is becoming increasingly problematic.

These difficulties and the increasing public perception that we are drowning in a sea of garbage have resulted in considerable pressure regarding the freedom to throw things away. We fear that we are running out of places to discard or store waste materials, damaging the environmental life-support systems on which we depend, and running out of resources. We have not yet experienced any serious difficulties in finding new supplies of materials, although their extraction and the wastes from extraction have posed local and regional environmental problems. An industrial system with open, linear materials flows—one that takes in materials, and energy, creates products and waste materials, and then throws most of them away—probably cannot continue indefinitely.

Industrial ecology is the study of industrial systems (materials and energy flows) from the perspective of natural ecosystems. The natural ecosystem has evolved so that any available source of useful material or energy is used by some organism in the system. Animals and plants live on each other and on each other's waste matter. Materials and energy tend to circulate in a complex web of interactions: Animal wastes and dead plant material are metabolized by microorganisms and turned into forms that are useful nutrients for plants. The plants, in turn, may be consumed by animals or simply die, decay, and cycle again through the system as nutrients and components of other flora and fauna. These systems do, of course, leave some waste materials, or fossil fuels would not exist. On the whole, the system regulates itself and consumes what it produces.

Can industrial systems be more self-sufficient and closed with regard to the flow of materials so that interactions with the environment are more compatible? The lessons of the planned economies of the former Soviet Union suggest that planning and controlling the industrial system is not the solution. Rather, we need to experiment with changes in policy and industrial practices to see what actions will nudge the system in the desired direction. These nudges must be regarded as experimental, to be adjusted in the light of experience (Frosch, 1996; Frosch and Gallopoulos, 1989; Frosch and Gallopoulos, 1992).

USING MATERIALS EFFICIENTLY

One way for industry to be more self-sufficient and closed is to improve the efficiency of materials use. Surprisingly, this obvious idea has not been much attempted. If material is bought at one end of the system and thrown away at the other, it is probably wasteful in the ordinary sense, and materials are not being used as efficiently as practicable.

In addition to the waste materials from production, the products themselves (which industrial firms generally do not regard as part of their system once they are sold) eventually become part of the waste stream of society. When products wear out or are replaced by newer models, they are usually thrown away. They may be used as landfill or incinerated or they may litter the landscape. It seems worthwhile to examine both production processes and product designs to see if the use of materials (and energy) can be improved.

Regulatory pressures and shifting public opinion have spurred the industrial and engineering community to initiate efforts aimed at closing the materials loops more effectively and improving energy-use efficiencies (Allenby and Richards, 1994; National Academy of Sciences, 1992; Richards and Frosch, 1994; Schmidheiny and the Business Council for Sustainable Development, 1992; Smart, 1992). Automobile manufacturers such as BMW and Volkswagen have designed cars for easy disassembly and recycling (Simon and Woodell, this volume). Companies such as Hewlett-Packard, Canon, and Xerox have begun to take back their own used components, such as toner cartridges, and to manufacture new ones using refurbished components and recycled materials from the old ones. By considering their leased and sold products as assests, these companies are designing new products with reuse, remanufacture, and recycling in mind. Even before these newly designed products have come to market, the change has resulted in cost savings (Murray, 1994; Richards and Frosch, 1994). At the 3M Corporation, a simple measure—waste mass divided by the total output mass (the sum of product, by-product, and waste masses)—is used to encourage materials-use efficiency (Richards and Frosch, 1994). Enterprising entrepreneurs are using recycled materials in innovative new products, such as textiles.

The industrial ecology perspective is beginning to influence designers of manufacturing processes to seriously consider waste streams. Designers of products are beginning to view their creations as transient embodiments of matter and energy with added value that can be recaptured and recreated within a continuing flow of materials extending beyond the point of sale. Products and the materials they contain are being designed so that they can be reused at the end of their lives.

The whole industrial process can be thought of as a closed cycle in which the manufacturer has overall custody for the material used. In this system, the manufacturer must consider the entire material and energy stream, from materials input and manufacturing through the life of the product and its eventual reuse or disposal. This concept has begun to be embodied in law (as in Germany), making manufacturers responsible for their products through to final disposition.

From a systems point of view, it is not clear whether it is most useful to consider the flow of materials at the level of an individual plant, a manufacturing firm, a group of firms engaged in producing a product, an industrial sector, or industrial activities as a whole. Suboptimization (i.e., optimization of a particular process or subsystem instead of the larger system in which the process or subsystem is embedded) may be less efficient than optimization of the larger-scale system. For example, a larger, more complex, more diverse system may offer a wider variety of opportunities for reuse of materials. More complete system closure may be attained by considering all of industry as the system to be optimized and closed rather than by considering a single firm, process or product.

Some of the complexity of the flow of materials through the U.S. industrial system is suggested by the case of lead (Figure 1). This attempt to follow the flow of materials through "industrial metabolism" (Ayres, 1989) shows that the recycling of spent consumer products already plays a major role in the U.S. lead industry.

PRODUCTS OR SERVICES?

Some firms have already begun to design their products and processes with a view to closing material loops as much as possible. However, if a product is the transient embodiment of materials to which a firm has already added value, then closing the loop on those value-added materials raises an important question for

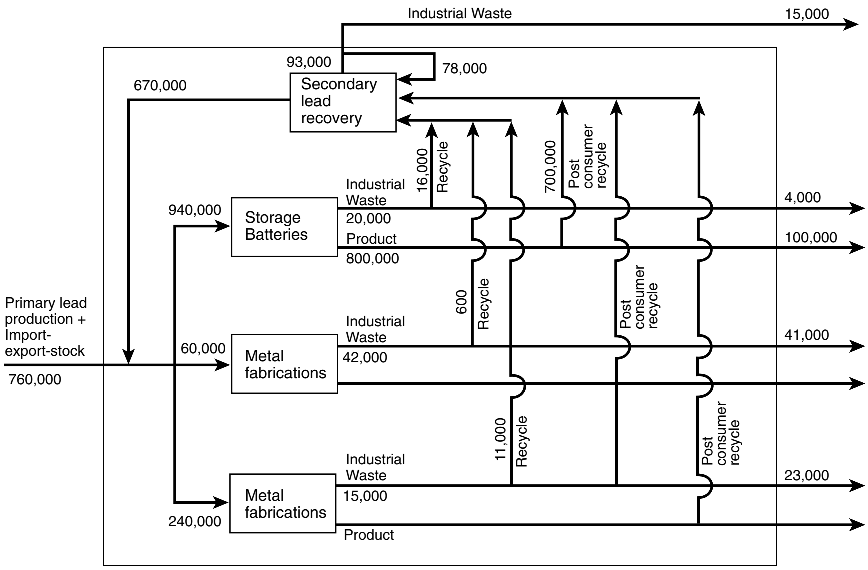


FIGURE 1 Simple model of the lead flows in the United States (metric tons/year). About 47 percent (670,000 tons) of the lead entering the U.S. market each year is from recycled sources. Almost 90 percent of the 800,000 tons per year that ends up in storage batteries is eventually recycled (16,000 tons of industrial waste from battery manufacture and 700,000 tons from post-consumer recycle). SOURCE: Allen and Behmanesh, 1994.

the firm: Is the product simply the hardware being sold, or is it rather the services that the product can provide? (Stahel, 1994; Stahel, this volume). There was a time when it was common practice to lease rather than sell many products outright. In a lease-based system, the manufacturer controls and therefore is responsible for the end of the product's life and is always prepared to take it back for recycling, reuse, or refurbishment.

Designing a product as a temporary provider of a service, to be used later in the creation of another product, is a novel idea in modern manufacturing and raises a new set of issues. A product is generally sold with the assumption that a consumer or sequence of consumers will use it until it cannot be used anymore. If the manufacturer thinks about taking it back for remanufacturing, the length of time the product spends in the customer's hands becomes an adjustable design variable. The maker may not want the product to wear out by being used for an indefinite time and so might choose to reclaim it at an optimum time for remanufacture. Thus, the notion of what a product is changes. Similarly, its life cycle may also change. The manufacturer may increasingly want to choose materials and designs that take serious account of eventual "demanufacture" and reuse. The various times involved in such a process can, of course, raise design conflicts.

BARRIERS TO INDUSTRIAL RECYCLING

Automobiles, their components, and other metal products, especially those made of iron and steel, have a long history of being recycled without regulatory prodding. (It was a common lament after Pearl Harbor that the Japanese fleet had been built mostly with American scrap metal.) For other products and materials, progress has come later and been much slower.

For example, wastes with a higher metal content than is found in commercial ores are often not recovered. Allen and Behmanesh (1994) demonstrated this by comparing concentrations of metals in waste streams against the Sherwood plot. For various nonferrous metals that are regularly recovered from scrap and waste, Figure 2 relates the market price of the pure metal against the minimum concentration of metal wastes undergoing recycling. The diagonal line in Figure 2 is known as the Sherwood plot, after Thomas Sherwood who in the 1950s pointed out the relation between the price of a metal and its concentration in commercially viable virgin ore. The few points below the Sherwood line in Figure 2 indicate metals (such as chromium and vanadium) that are being vigorously re-

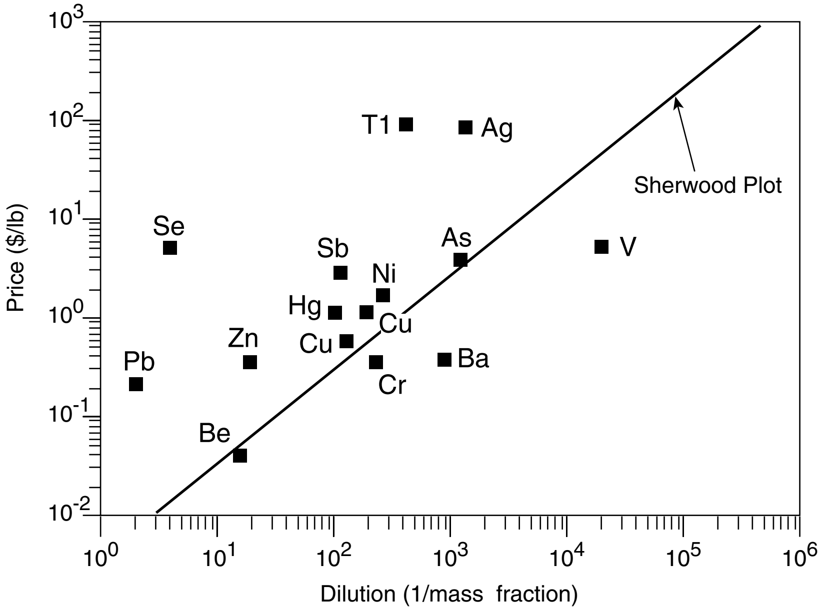


FIGURE 2 The Sherwood plot for waste streams. The diagonal line (Sherwood plot) correlates concentration of metal in commercial ores to market price of metals. Points above the Sherwood plot indicate metals in waste streams that are richer than typical virgin ores being disposed of. Points below the Sherwood plot indicate metals that are vigorously being recycled from industrial hazardous waste streams. SOURCE: Allen and Behmanesh, 1994.

cycled. Points far above the Sherwood line indicate underexploited metallic waste streams. Aluminum, although not shown in this Sherwood diagram, has been very heavily recycled in recent years. In the case of aluminum, the energy cost of electrolytic extraction from the ore is much higher than the energy cost of recycling used soda cans.

Why is there so much waste, especially of iron, steel, and precious metals, in the metal industry, which has such a long tradition of recycling? The barriers to industrial recycling of metals can be classified into six interrelated areas: technical hurdles, economic barriers, information barriers, organizational obstacles, regulatory issues, and legal concerns. When recycling is technically feasible, it may be economically unsound. When it is technically and economically satisfactory, a lack of information may block its adoption. Even when the requisite information is at hand, organizational problems can still stymie implementation. Finally, when all else is satisfactory, a recycling scheme can founder on the rocks of regulatory or other legal barriers.

Technical Hurdles

The suitability of the material for an intended reuse is a key technical concern. Metals, metal compounds, and organic materials make up a large fraction of industrial products. The metals are relatively easy to reprocess and reuse. In many cases, however, organic materials are best thought of as energy stored in chemical bonds (largely carbon bonds) rather than as reusable materials; they are generally exothermically oxidizable. The choice between recycling the material and burning it as fuel or otherwise extracting its chemical energy might be made on the basis of comparative market values.

Waste and product materials sometimes contain unwanted "tramp" elements. These contaminants can ruin the reuse potential of the materials or make handling difficult or dangerous; purification is often problematic. As products are redesigned for newer more cyclical material use, some of the material problems may be eliminated through smarter design. However, it will not always be possible to "design out" problematic materials. For example, zinc is often used to coat steel to prevent corrosion. It can interfere with the desirable properties of new steel forged from melted recycled scrap steel. Steel mills therefore limit the permissible content of zinc in the scrap they buy or they pay less for scrap with more than a threshold concentration of zinc. Such matters are generally handled by scrap dealers, who blend zinc-free and zinc-coated scrap in the mix they sell to the mills. In the long run, this practice may lead to a zinc contamination problem in the steel-scrap recycling business, but there are no good, inexpensive substitutes for zinc as an anticorrosion coating. The blending process is sometimes regarded as a case of sham recycling, because the zinc is not being recycled. One could say that it is being disposed of in the steel. Such sham recycling, however, may be preferable to uncontrolled releases of zinc to the environment.

Economic Barriers

The manufacturing process tends to mix materials that are further mixed in the process of waste disposal. In remanufacturing, one generally wants to separate things into their original components and materials. There are costs involved in collecting, sorting, and transporting used-up products, scrap, and waste. Such separation requires information, effort, and energy, which must all be paid for. These costs must be compared with the costs of new materials.

Even when the operating costs of recycling are attractive, there may be capital costs that pose barriers. Heavy capital investment in existing systems may prevent a company from securing an easy source of new investment to start over. This obstacle may only introduce a time lag, postponing the decision to recycle until it is suitable to make a capital investment, such as when the machinery requires change for some other reason. Some companies that face competitive forces of ever-shorter product times, particularly those in the electronics industry, have introduced "design for the environment" techniques as a major impetus for reengineering their products and processes.

The cost of eliminating or reusing certain materials must be balanced against the cost of disposal. Disposal costs bring up the question of how companies should take account of indirect costs such as the effect of wastes on the environment. These issues have generally been handled by regulatory control of emissions but could equally be dealt with by including the costs of environmental damage in a firm's bookkeeping (Macve, this volume; Todd, 1994). The bookkeeping approach would provide an incentive to minimize such costs, and it might force a truer comparison of the costs of alternative schemes. However, it has proved very difficult to find suitable, agreed-upon measures for such costs.

Information Barriers

The requisite information about costs is not usually available to everyone in the firm who might be able to use it to good advantage. It is sometimes not clear who might need the information, and standard management and other accounting systems often do not track costs in a way that is useful to designers. Design engineers may not know of the real costs to the company of the materials they choose because costs usually appear as prices offered by the suppliers. Designers generally have no idea what waste problems will be posed by manufacturing with different materials. Better systems for acquiring and disseminating cost information within firms are needed.

In the larger economy, outside the firm, where waste and scrap materials may be transferred and used, information is needed about potential customers and suppliers of these materials. In traditional metal-recycling sectors, complex, multitier networks of scrap collectors, sorters, brokers, alloyers, refiners, and smelters serve as the information network. Business and trade organizations, such as the Institute of Scrap Recycling Industries and the Steel Can Recyclers Institute, also provide information. In newer areas of recycling, such as plastics, adequate informational and organizational mechanisms are yet to evolve.

In materials sectors where traditional recycling networks do not exist, information may be difficult to find, especially if users and providers are in very different geographical areas or different parts of the industrial system. Existing waste exchanges and brokerage systems are generally small, local, and ineffective on a large scale. Attempts are being made to create better market arrangements. The Recycling Advisory Council and the Chicago Board of Trade, with the support of the U.S. Environmental Protection Agency, are seeking to create an exchange market on an electronic bulletin board. This market would initially trade in glass, polyethylene terephthalate, and high-density polyethylene. Some metal recyclers, stimulated by public opinion and the resulting anticipation of new recycling markets, are expanding into other materials to fill the gap (Kisser, 1994).

Organizational Obstacles

The internal organization of a firm can be difficult to change. Changing the whole concept of a product or adding new criteria for environmental compatibility to the design process may not fit the ideas on which the firm operates or its internal incentive system. The business-unit structure may make perception and solution of problems that cross organization lines very difficult.

External to a firm, the idea that anything secondhand must be second rate has become institutionalized in the distinction between dealers in new and the used materials and products. Organizational issues can plague not only the establishment of markets, but also the creation of new institutions such as information and waste exchanges and larger-scale brokerages.

Regulatory Issues

The U.S. regulatory system for industrial wastes has been designed around disposal, and the rules treat recycling and reuse as forms of disposal. The designation of a material as waste, as distinguished from scrap or hazardous material, can be crucial.

There are many inconsistencies in the Resource Conservation and Recovery Act. For example, the waste classification of a solvent-laden rag used to clean machinery depends on how it was used. If the solvent is poured first on the machinery and then wiped with a clean rag, the rag is a hazardous waste. However, if the solvent is poured first on the rag and then the rag is used to wipe the machinery clean, the rag is not considered a hazardous waste (Starr et al., 1994).

Recycling an industrial waste material is likely to require the recycler to become a legal disposer of that material under the regulations. Obtaining a permit has significant time, financial, and bureaucratic costs attached, which are a nontrivial barrier to reuse of industrial waste materials (Scrap Processing and Recycling, 1994).

A characteristic tale from industry is illustrative of the problems facing those firms that attempt to use materials more efficiently. The corrosion coating of auto bodies is accomplished by passing the cars through a zinc phosphate bath. After a period of use, the bottom of the bath contains a slurry rich in zinc. At one plant, this slurry was for many years removed periodically when the tanks were cleaned and then sent to a zinc smelter, which processed it and put the resulting zinc metal back into the industry supply stream. In the course of regulatory actions not aimed at this material, the slurry became classified as a hazardous waste. When the smelter became acquainted with the regulations that would now apply, it refused to accept the material any longer. At the time this anecdote was told, the slurry was being sent to a landfill.

Such problems are frequently solved by getting waivers or exceptions to cover the particular case, but the process is very cumbersome. The details of such problems may differ from state to state, and state regulations can be even more restrictive than federal regulations.

Waste is regulated separately from new materials. The system for control of virgin toxic materials is not nearly as cumbersome as that for waste materials. It is difficult, for example, to dispose of waste cyanide or send it for reuse, but it is easy to purchase new cyanide from a chemical manufacturer. Such regulations were intended to encourage environmentally cleaner technology by making disposal difficult and expensive. Although it makes good sense to control through reuse and recycling hazardous waste materials, in practice the system inadvertently encourages the use of new materials and the disposal of old materials.

A recent initiative by the EPA administrator seeks to change the regulatory system toward coordinated regulation of an industry rather than regulation determined simply by the material or medium in question. Such a system, it is hoped, would cope better with the realities of manufacturing and industrial life (Environmental Protection Agency, 1994).

Legal Concerns

Under current legal practice, liability considerations for a hazardous material often favor its disposal over its sale or transfer for reuse. Liability is often targeted at the original seller of any material used in a product implicated in a damage suit, even if the material has been reused and remanufactured by several parties en route to that ultimate product. The trail of potential liability can be so long and so unpredictable as to be thoroughly unpalatable. Furthermore, under the current practice of "joint and several" liability, damages in a lawsuit may be distributed according to the depths of the pockets of the various parties rather than their responsibility for the harm.

A supplier of a generally harmless, minor component material in a product might be assessed high liability damages because the product caused harm, even if that supplier was not a party to the product design and the material was not at fault. This practice has serious implications for commerce generally, and it appears to explain why firms often choose to dispose of scrap and waste rather than seek users for them.

The following example from a glassmaker is illustrative. Certain nonhazardous wastes from glassmaking would make good additions to concrete, improving its properties. Nevertheless the glassmaker disposes of these wastes in a landfill, because the firms's legal counsel worries about potential liabilities if the concrete ends up in an apartment house or a highway. Such liability risks are hard to predict and quite unacceptable in comparison with the more predictable liabilities related to landfill disposal. Elsewhere in the same industry, however, glass scrap is routinely added to asphalt road-paving material, giving rise to the name "glasphalt".

A shift from selling goods to leasing the services they provide could raise antitrust issues, because leasing can imply greater control of the product market. Separation of wholesale and retail sales organizations was an issue in the IBM and AT&T antitrust actions of recent years, and in the separation of automotive manufacturers from their dealership systems.

CLOSING THE LOOP

Industrial ecology views industry's impact on the environment in terms of a comprehensive system that uses and disposes of materials. We can learn to close the materials loop more efficiently by thinking on a larger scale about the flow back into industry of materials that would otherwise be discarded into the environment. There are numerous means of protecting the environment from industrial wastes. We can, for example, forgo the benefits of a potentially harmful material or we can seek to replace it with a more benign substitute. We can redesign products with a view to reusing materials and components. It is not yet clear what mix of remedies will most economically minimize the impact of industrial materials on the environment. The various possibilities hold out great promise, but there are complex problems and barriers to be overcome as we develop and implement a new, ecologically sound model for the management of materials in industry.

REFERENCES

Allen, D., and N. Behmanesh. 1994. Wastes as Raw Materials. Pp. 69–89 in The Greening of Industrial Ecosystems, B. R. Allenby and D. J. Richards, eds. Washington, D.C.: National Academy Press.

Allenby, B. R., and D. J. Richards, eds. 1994. The Greening of Industrial Ecosystems. Washington, D.C.: National Academy Press.

Ayres, R. U. 1989. Industrial metabolism. Pp. 23–49 in Technology and Environment, J. H. Ausubel and H. E. Sladovich, eds. Washington, D.C.: National Academy Press.

Environmental Protection Agency. 1994. Browner names six industries in plan to improve environmental protection. Press release. Environmental Protection Agency: Washington, D.C.

Frosch, R. A. 1996. Toward the End of Waste. Reflections on a New Ecology of Industry. Pp. 165–175 in Technology Trajectories and the Human Environment, J. H. Ausubel, D. Langford, eds. Washington, D.C.: National Academy Press.

Frosch, R. A., and N. E. Gallopoulos. 1989. Strategies for manufacturing. Scientific American 260:144–152.

Frosch, R. A., and N. E. Gallopoulos. 1992. Towards an Industrial Ecology. Pp. 269–292 in The Treatment and Handling of Wastes. A. D. Bradshaw, R. Southwood, and F. Warner, eds. London: Chapman and Hall.

Kisser, K. 1994. Scrap Processing and Recycling 51(3):74.

Murray, F. E. S. 1994. Xerox: Design for the Environment. Harvard Business School case N9-794-022. Cambridge, Mass.: Harvard Business School.

National Academy of Sciences. 1992. Proceedings of the National Academy of Sciences. 89: 793–884.

Richards, D. J., and R. A. Frosch, eds. 1994. Corporate Environmental Practices: Climbing the Learning Curve. Washington, D.C.: National Academy Press.

Schmidheiny, S., and the Business Council for Sustainable Development. 1993. Changing course: A global business perspective on development and the environment. Boston: Massachusetts Institute of Technology Press.

Scrap Processing and Recycling. 1994. 51(3):11.

Smart, B. 1992. Beyond Compliance. Washington, D.C.: World Resources Institute.

Stahel, W. 1994. The utilization-focused service economy: Resource efficiency and product-life extension. Pp. 178–190 in The Greening of Industrial Ecosystems, B. R. Allenby and D. J. Richards, eds. Washington, D.C.: National Academy Press.

Starr, J. W., J. G. Block, and J. F. Cooney. 1994. Legal Times, May 31:6.

Todd, R. 1994. Zero-loss environmental accounting systems. Pp. 191–200 in The Greening of Industrial Ecosystems, B. R. Allenby and D. J. Richards, eds. Washington, D.C.: National Academy Press.

The Industrial Green Game. 1997. Pp. 48–72.
Washington, DC: National Academy Press.

Metrics, Systems, and Technological Choices

DAVID REJESKI

He who avoids new remedies, must expect evils, for time is the greatest innovator.

Francis Bacon

The sustainability of the biosphere by efficient and equitable use of planetary resources has become an important cornerstone of a number of national and international policy statements. Though sustainable development will depend on a more environmentally robust industrial ecology, the ecological restructuring of industry will also depend on a sustainable infrastructure for energy and other critical resources at multiple levels. Governments play an important role in the development, maintenance, and social and technological transformation of such infrastructures. To help support an environmentally sustainable industrial ecology, national governments need to change fundamentally their systems of national accounts, analyze and improve critical metabolic processes, and explore emerging technological paradigms and their implications for sustainable development. Such tasks need to be undertaken in partnership with industry and with the support and consent of the public at large.

Much of the discussion about the role of the government in industrial ecology has focused on the use of economic instruments (pollution taxes and markets, tax credits, deposit refund schemes, etc.) and regulatory frameworks (take-back regulations) to provide incentives for industry and consumers to move in more ecologically sound directions. There also have been proposals to encourage collaboration among industries and between academia and industry (Weinberg et al., 1994). Such policies are important but are insufficient for avoiding new evils. By placing the government in the role of benevolent steersman, one runs the

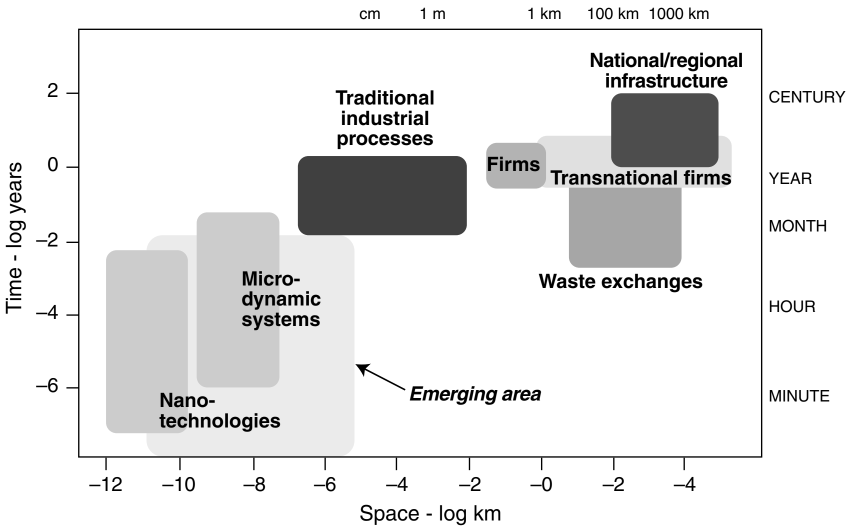


FIGURE 1 Space-time hierarchy of industrial systems. SOURCE: Adapted from Holling, 1992.

danger of confusing the navigator with the oarsman. As we attempt to steer industry in the right direction, we may loose sight of the larger policy horizon critical for systems navigation.

This paper argues that national governments must go beyond the study and improvement of industry's ecology and apply similar principles and paradigms to nations as a whole. This will involve adapting a systems-ecology view of human and economic activity across multiple scales.

There are several interlocking rationales for advocating a broader government role in industrial ecology. From an ecological perspective, one must acknowledge that there are obvious limits to applying ecological and biological analogies to socially contrived systems such as industry or governments. Ecologists have noted that society is facing a new class of problems that are fundamentally cross scale in space as well as time (Holling, 1992). These problems are not susceptible to reductionist analysis or the simple optimization of subsystems. They must be approached with a healthy suspicion of parochial solutions and a skepticism of what single organizations can accomplish. Figure 1 illustrates a potential space-time hierarchy of industrial, or industry-relevant, systems (adapted from Holling, 1992). Similar hierarchies are exhibited by ecological phenomena and natural systems, such as weather. The time axis refers very roughly to the average time required for significant structural change (e.g., the time require to develop new products, transform organizations, and build new infrastructures—

essentially the tranformational life cycle of products, processes, organizations, and infrastructures).

Ecological theory, if it holds, would predict that this is a loosely coupled system that exhibits assymetrical interactions between levels (Allen and Starr, 1982). Normally, large, slower systems set the boundaries in which faster, smaller systems operate. The experimental and creative latitude of firms is often limited by physical, economic, and policy or regulatory infrastructures, which may require decades to change. However, a bottoms-up asymmetry can establish itself when the larger systems become tightly coupled and brittle or during periods of reorganization. In such times, small events can affect large systems. Advances in microdynamic systems, nanotechnologies, advanced materials, genetic engineering, or information systems and potential new ways of organizing and managing the production processes around these technologies could have significant bottoms-up impacts on the whole system. The "greening" of the industrial system means the greening of this space-time hierarchy from the level of the nation to that of micro- or nanoscale production.

Ultimately, this will involve the joint optimization of technical and social systems at different time periods and geographic scales and the solution of a number of what some observers have termed "messes," or systems of problems (Ackoff, 1981). The significance of such systems is that normal approaches to problem solving and policy making, which break problems into parts and solve each part, will not work. Systems-based problems require a fundamental shift in the mental models used by decision-makers at different organizational levels, from business managers to government policymakers and research scientists. The mess we must extricate ourselves from involves helping private- and public-sector organizations to learn their way out of dysfunctional, nonecological, nonsustainable ways of doing business. The adaption of a holistic, ecological perspective is only likely to occur in organizations that have learned to learn, where values, operating assumptions, and frames of reference are questioned and changed as needed. Unfortunately, large bureaucracies may be the ultimate prototype for organizations with learning impairments.[1] For this reason, industrial ecology must deal not only with industrial organizations, but also with macrosocial systems, such as governments. The public and private sectors must work together to transform the intellectual and political ecology underlying our systems of materials and energy transformation at multiple scales.

Much of the research and application of industrial ecology has been focused on the level of the firm or the internal processes of the firm. The greening of our industrial infrastructure cannot be limited to solving firm-level problems alone, because all firms are embedded in larger physical, economic, and organizational systems and metasystems. These can continue to function in nonecological and nonsustainable ways outside of the influence of industry. This paper focuses on the national infrastructures in which firms operate.[2] To support an evolving industrial ecology at a global scale, governments must fundamentally alter their systems of national accounts, analyze and continually improve their metabolic processes, explore emerging technological paradigms, and seek sustainable development paths. This is obviously a large agenda and can only be presented in cursory form. Seeking new remedies will require leadership on the part of government, strong partnerships with industry, and an informed and engaged citizenry. These changes are explored in three short essays.

ESSAY 1: THE SEARCH FOR NEW METRICS

In politics, numbers beat no numbers every time.

Jodie Allen, former U.S. assistant secretary of labor

The Swedish economist Gunnar Myrdal once remarked that the question must be asked before the answer can be sought. The existing system of national accounts does not ask any ecologically relevant question, nor does it provide any answers to fundamental issues of industrial transformation and sustainable development. The application of traditional macroeconomic indicators will not guarantee environmentally benign or sustainable development because the conventional measures of national economic performance (such as gross domestic product [GDP]) fail to measure adequately human, social, and ecological welfare. In addition, they often treat different forms of wealth differently and inconsistently and neglect inputs and outputs that are not marketed, leaving large parts of the economy and biophysical infrastructure unmeasured. One can trace the development of these accounting systems and the relationship among economic growth, resources use, and environmental pollution they imply through four distinct phases (Colby, 1990). Although one must be cautious when using this analogy across scales and institutions, similar patterns can be observed at the level of the firm.[3]

The first phase described by some economists as "frontier economics" describes a well-known situation in which profits are maximized with little or no concern for environmental impacts or the efficiency of resource use (Figure 2A). Essentially, concerns for environment and resources remain external to the calculus allowing environmentally rapacious behavior to go unnoticed or actually registered as a net economic gain.

This phase was replaced during the 1960s and 1970s in many developed countries by a phase of environmental protection, where increased reliance on command-and-control policies and assorted end-of-pipe controls allowed certain types of pollution to be decoupled from economic growth and output (Figure 2B). This decoupling is not, however, invariate. Cross-national studies by the World Bank have shown that certain environmental problems (e.g., carbon dioxide and solid waste) actual worsen with increasing economic growth, suggesting that much more aggressive policies aimed at decarbonization (use of less carbon per unit of energy produced) and dematerialization (use of less material per unit product) may be needed (Ausubel et al., 1989; Shafik, 1994). The third phase, termed resource management, focuses on the decoupling of natural resource use from economic productivity (Figure 2C). Such decoupling may not be the result of any conscious environmental policies but may be the gratis effect of structural changes in the economy itself and the underlying systems of production (e.g., a shift to a service-based economy). There is significant debate about the limits of decoupling inputs from economic growth. Evidence indicates the ability of humans to create man-made goods that will substitute for natural resources and capital may not be as great as some neoclassical economists would like us to believe (Georgescu-Roegen, 1979). However, there is little doubt that existing efficiencies of resource use can be improved considerably within the limits set by fundamental thermodynamic laws.

The final phase has been termed ecodevelopment, or sustainable development, and clearly represents the measurement approach required to support a sustainable industrial ecology at multiple scales (Figure 2D). This approach involves correctly gauging the total environmental costs of the nation (and of the firm) and recognizing that the traditional measures of economic growth and progress are often flawed and must be modified. Modifications normally fall into two broad categories that involve the inclusion of natural capital, and its depreciation, in the balance sheets as well as the subtraction of remediation costs and monetized environmental damages.[4] Some have termed this approach, which provides a true ecological perspective to whole economic and social systems, "ecologizing the economy" (Colby, 1990). Attempts to improve accounting methodologies range from natural resource inventories used in Norway (Alfsen et al., 1987) to fully integrated approaches for calculating sustainable national incomes being developed and applied in the Netherlands (Folke and Kaberger, 1991; Hueting et al., 1991).

Once the measures of economic growth have been modified, the question of whether resource use, though decoupled from growth, is at sustainable levels (i.e., whether rates of extraction and use equal rates of regeneration or substitution) must be dealt with. There is an obvious danger in running an economy on nonrenewable resource inputs. In the United States, a smaller fraction of primary material needs has been met by renewable resources since the turn of the century, and a significant increase in the use of nonrenewable feedstocks in the production of such secondary materials as asphalt, plastics, fiber, and petrochemicals has also occurred (Figure 3) (U.S. Bureau of Mines, 1991). Recycling has changed that picture somewhat during the past decades, but the United States still remains extremely dependent on the flow of nonrenewable materials into its economy.

Systems dependent on nonrenewable feedstocks or systems that continuously overdraw renewable resources flirt with a number of dangers. There is an unfortunate tendency to confuse rates of discovery with actual rates of replacement of resources. This can lead ecosystems and industrial ecosystems into serial traps. Such traps occur when the replacement rate of resources is exceeded by the use rate and resource depletion cumulatively affects availability, resulting in intensi-

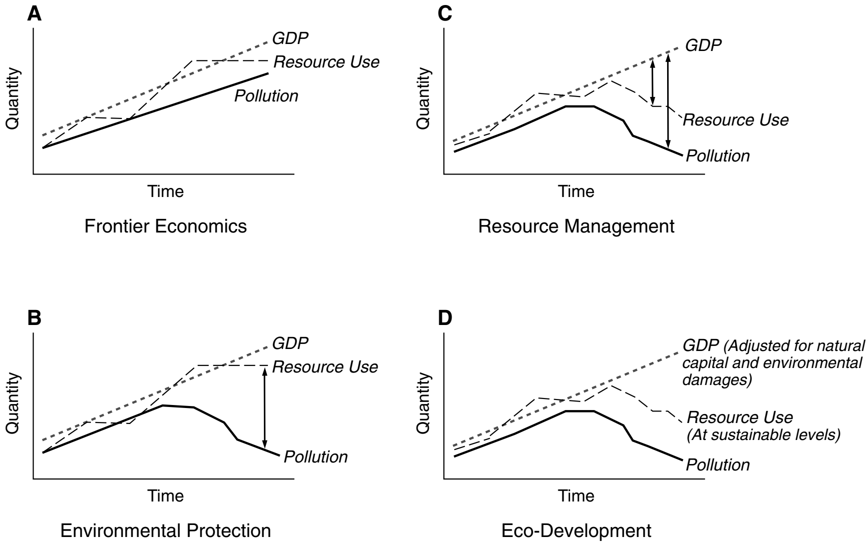


FIGURE 2 Development of accounting systems. SOURCE: Colby, 1990.

fying scarcity and irreversible damage and collapse (Freese, 1985). Modeling industrial systems after ecosystems does not guarantee success, because various species such as birds and caribou are subject to such overuse and crash phenomena, and human-dominated systems may not be immune to such traps. For this reason, attempts to calculate (even very roughly) the sustainable levels of resource use and incorporate these measures into accounting systems at multiple levels are crucial. In approaching this task, we must be explicit about our assumptions concerning natural-resource saving technologies and our future ability to substitute labor and reproducible capital for exhaustible resources. As economist Robert Solow once remarked, “Someone...must always be taking the long view. They must somehow notice in advance that the resource economy is moving along a path that is bound to end in disequilibrium of some extreme kind” (Solow, 1974).

In general, we need accounting systems that allow us to track our progress toward a more sustainable economy with a shift away from nonrenewable inputs, increased recycling of waste streams, and the use of renewable resources at sustainable levels. The application of such accounting systems should be coordinated to allow the measurement of environmental-economic performance across industries, regions, and countries.

Country data can be used to examine where different countries lie on this continuum of accounting systems (Figure 4). For instance, the former Czech Republic typified a frontier economy, though economic reforms and recent changes in resource pricing in some former east block countries, such as Poland,

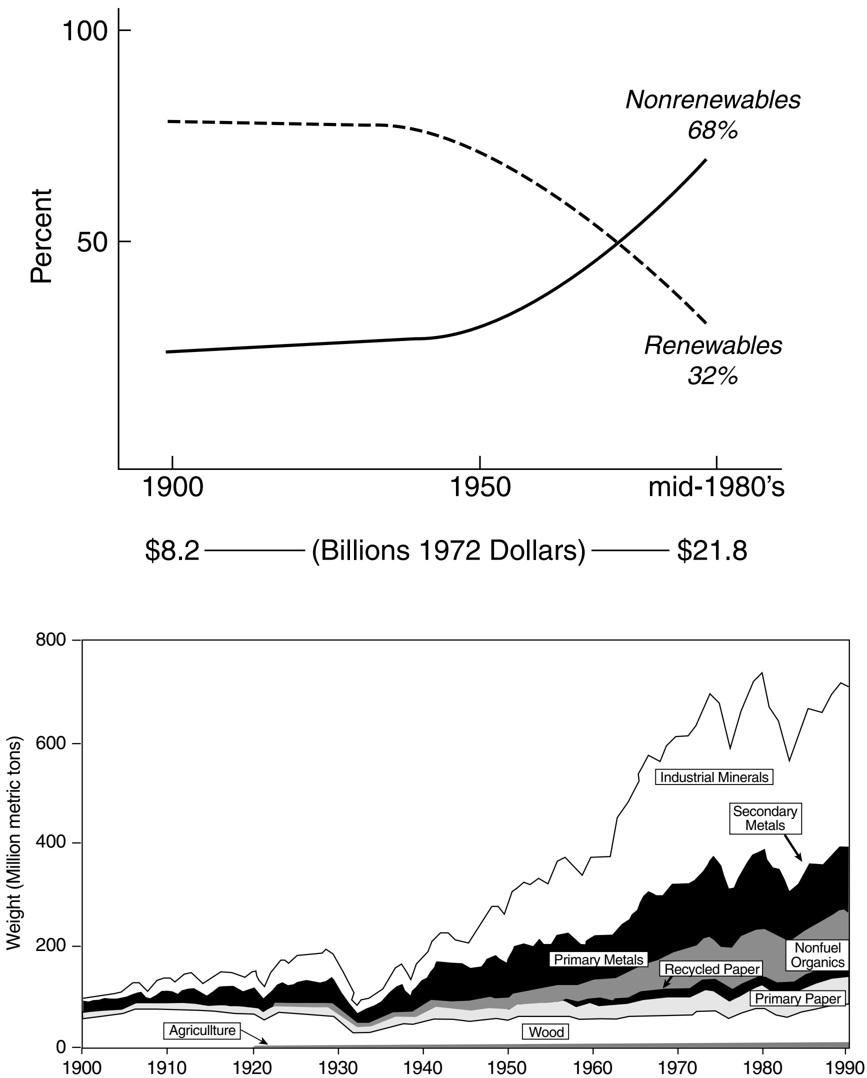


FIGURE 3 Changes in resource use in the United States from 1900 to the mid-1980s. SOURCE: U.S. Bureau of Mines, 1991.

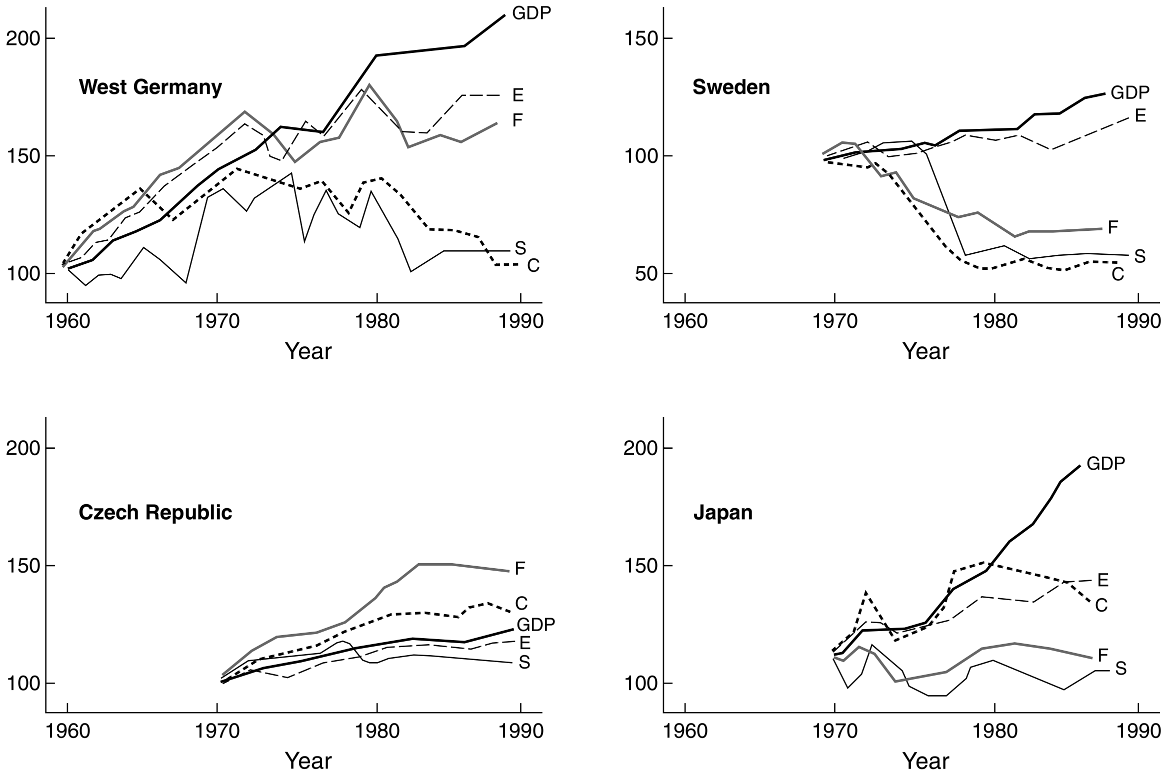


FIGURE 4 Select industrial structural changes in West Germany, Sweden, the Czech Republic, and Japan. GDP = Gross Domestic Product; E = Energy Consumption; F = Weight of Freight Transportation; S = Crude Steel Consumption; C = Cement Consumption. NOTE: For all countries except West Germany, 1970 = 100. For West Germany, 1960 = 100. SOURCE: Jaenicke et al., 1989.

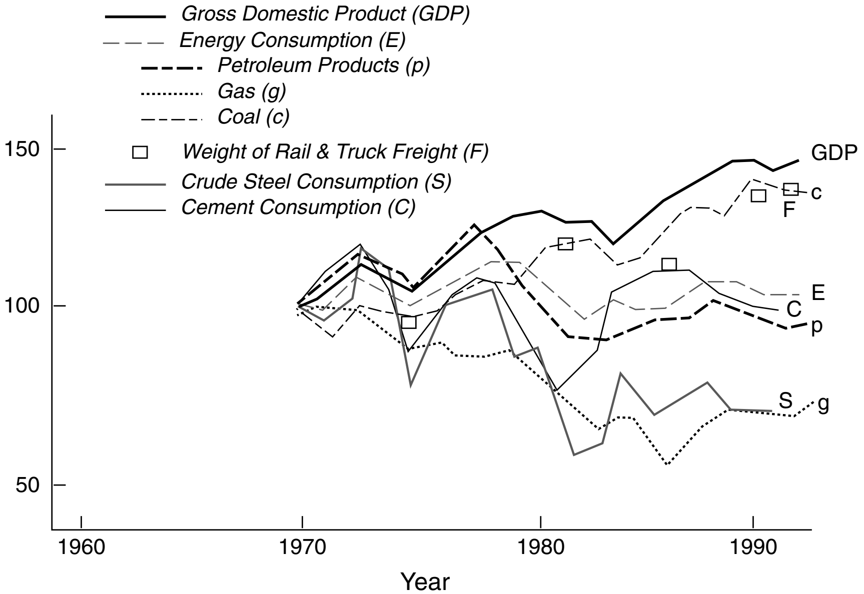


FIGURE 5 Select industrial structural changes in the United States (1970=100). SOURCE: Jaenicke, et al., 1989.

are leading toward greater resource-use efficiency. For many Western, developed countries, a decoupling of energy and the resource-intensive production of commodities such as steel and cement began with the oil price hike by the Organization of Petroleum Exporting Countries in the early 1970s. In many cases, this decoupling trend was further intensified by an expansion of a service economy. (Sweden provides an extreme example of this phenomenon.) The United States presents a mixed picture (Figure 5). Decoupling of energy, steel, and cement consumption occurred beginning in the 1970s, but a breakdown of energy consumption by fuel type shows much stronger decoupling for oil and gas than for coal. Also, the weight of rail and truck freight has increased in lock-step with GDP, which may roughly indicate the spatial separation of production from consumption.

Though helpful, such analyses are only the beginning. Additional questions need to be asked and answered. For instance, high levels of population growth may neutralize relative per capita structural changes, even though absolute improvements occur. Material and energy substitution effects need to be considered because decreases in the consumption of one material can be negated by corresponding increases in substitutes (plastics for steel, glass fiber for copper, etc.). Finally, regardless of substitution patterns, resources still may be consumed at levels that cannot be sustained indefinitely.

Despite the deficiencies inherent in any measurement system, the development, harmonization, and application of a full-cost accounting system for industries and nations must be accelerated.[5] Projects such as the National Environmental Performance Review of the Organization for Economic Cooperation and Development need to be expanded both geographically and conceptually along with country-specific projects to develop a green GDP. Ultimately, the quest for a sustainable industrial ecology will be aided by an intelligent search for a sustainable economy. This search must begin by asking and answering the right questions.

ESSAY 2: THE METABOLISM OF THE NATION STATE

You, the engineers and managers and bureaucrats, almost alone among men of higher intelligence, have continued to believe that the condition of man improves in direct ratio to the energy and devices for using energy put at his disposal.

Kurt Vonnegut, The Player Piano

The goal of greening all major systems of energy and materials transformations within nations and between nations requires the study of major social and institutional systems set up with the implicit, or explicit, goal of transforming key resource inputs into services for society. An important analytical approach will be to map the metabolic activity of these systems with the aim of improving resource, environmental, and economic efficiencies and exploring new options for providing fundamental services to society.[6] Such mappings need to take place at various scales--from processes to industries, urban environments, and regions and nations--and embody both supply- and demand-side perspectives. This higher-level perspective is required because most firms are embedded in and dependent on larger systems of transformation for energy, transportation services, materials, water and wastewater treatment, etc.

The flow of energy through the United States economy illustrates such an approach (Figure 6).[7] This typifies an industrial ecology characterized by linear, one-way flows and large uncaptured waste streams. It exhibits very low system efficiencies when viewed from the standpoint of the services delivered to society (mobility, heat, light, commodities, etc.).

In the transportation sector, for instance, only 1.6 quadrillion British Thermal Units (quads) of useful service are being derived from an input of almost 20 quads. Nine quads of waste heat flows from the engine blocks of internal combustion engines alone, and another 3 quads are being lost through idling and traffic jams. This analysis obviously forces one to take a close look at the limitations of the spark-ignition heat engine as a prime mover in the transportation sector. Both the thermal and mechanical efficiencies of the internal combustion engine can be increased through improving combustion, reducing friction, and

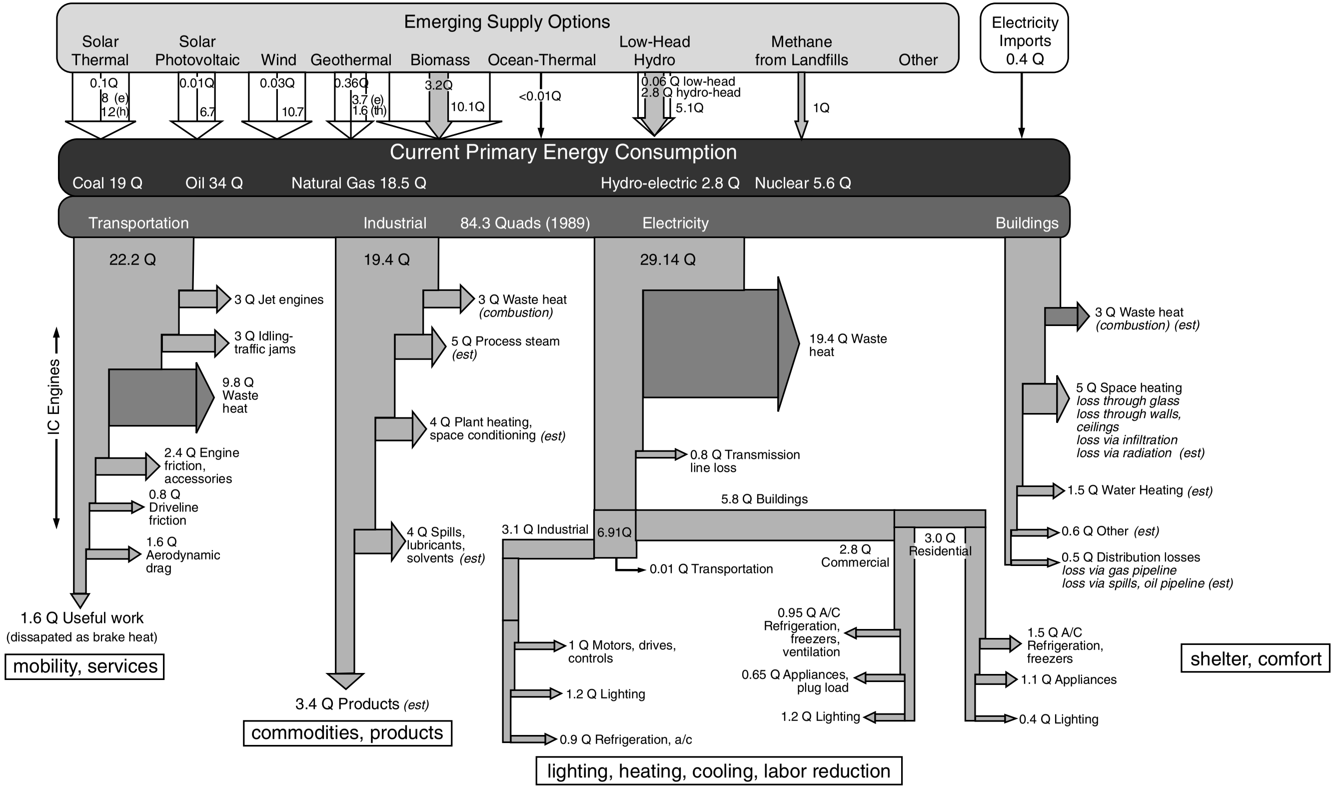


FIGURE 6 United States energy system. NOTE: Q = 1 quadrillion Btu. SOURCES: Blair, 1991; Council on Environmental Quality, 1989; MacCready, 1991; U.S. Department of Energy, 1990, 1991; TRW/US-ERDA, 1977; U.S. Environmental Protection Agency, 1989. Figure supplied courtesy of David Bassett, U.S. Department of Energy.

decreasing heat loss, but many of these techniques have high costs or environmental down sides. Some obvious technological alternatives, such as the orbital two-stroke engine, increase efficiency at the cost of emissions. That leaves us in the near term with tighter tolerances, better fuel injection, and cleaner fuels, but the long-term technology options have yet to be fully explored and chosen.

If one flips this model on its head and begins with the services delivered by this infrastructure, the way to provide mobility and access may not be vehicles with engines. This is an important point because a meaningful industrial system cannot be built solely on a calculus of supply-side efficiency. One must consider the ecological restructuring of the demand profile, exploring ways to provide essential services with new institutional and technological approaches.

In the electricity sector, the amount of waste heat from the mechanical conversion of steam to electricity is almost 20 quads more than the primary energy consumption of Japan. The options here to improve efficiencies include shifts to electrochemical conversion (fuel cells), district heating, and co-location, options that have been pursued for many years in Japan and many European and Nordic counties. Again, an end-use perspective of the electricity sector indicates that the options are not lightbulbs or energy-saving lightbulbs, but lightbulbs and better ways of using daylight in buildings; not air conditioning with or without chloroflurocarbons (stratospheric ozone depleters), but air conditioning and better techniques for natural ventilation. In many cases, the wider range of end-use options will include energy conservation technologies and knowledge-based solutions.

The last point from Figure 6 is that renewable supply options, except for low-head hydroelectric, remain vastly underused (the small lines within the larger arrows show used vs. potential resource). From an ecological perspective, this system exists on nonrenewable feedstocks, with renewables making up less than 10 percent of the primary energy consumption.

How does one understand this system and its historical evolution? A fundamental lesson is that money can drive metabolism in strange ways. The structure and inflexibility of such systems of physical transformation can only be understood by studying the long-term spending habits of organizations influencing their evolution—essentially, the political ecology of capital. A second-tier metabolism transforms monetary inputs into policies, actions, and structures. These flows need to be examined as carefully as are traditional resource flows. Figure 7 shows the flows of money, in terms of federal research and development (R&D) funding, into the U.S. energy system. One is immediately struck by the enormous difference in investments in demand-side vs. supply-side options and low funding for renewable options. Comparisons of these data with budget breakdowns going back to the end of World War II (see pie chart) indicate very little change in the distribution of applied R&D funds among primary energy sources.

Public investments in R&D are only one part of the picture. Figure 8 shows the pattern of subsidies that flow into the U.S. energy system (described in Figure

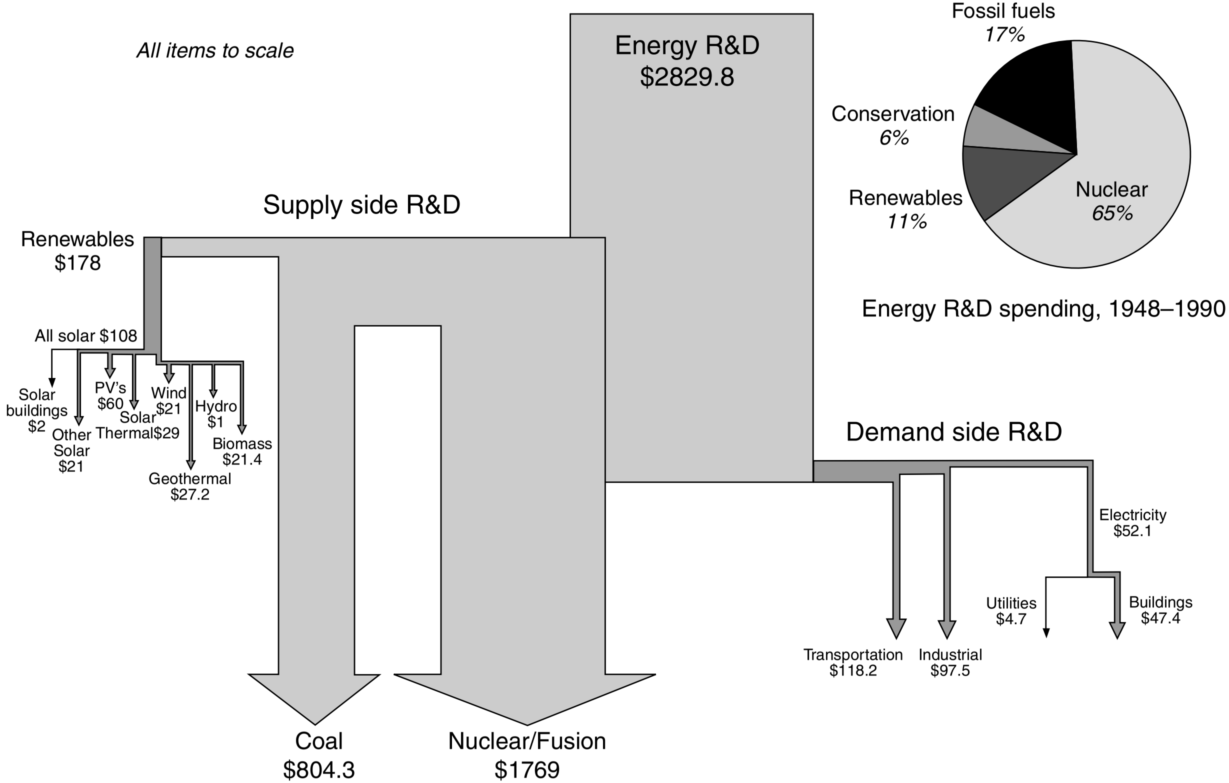


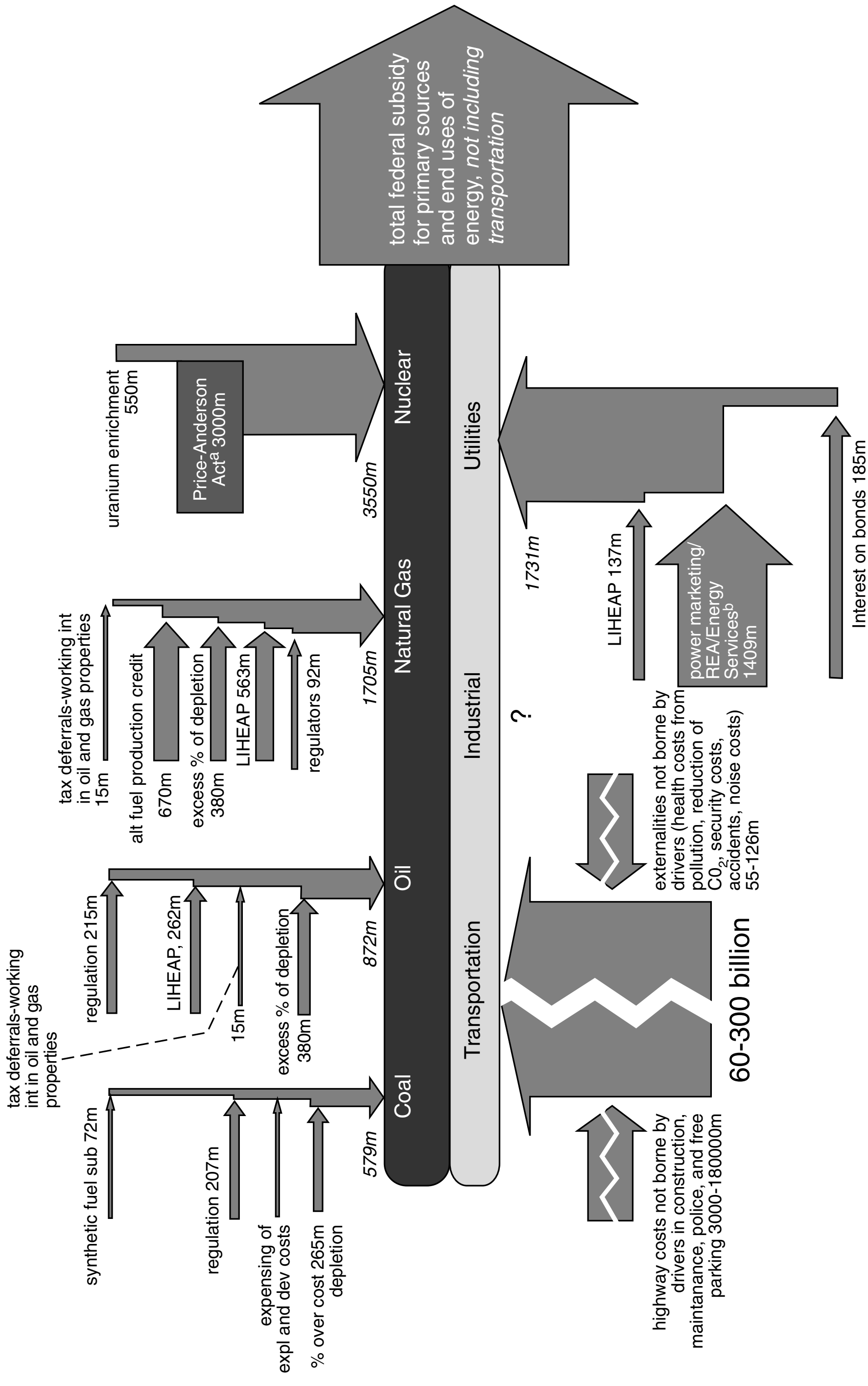
FIGURE 7 Federal applied energy research and development appropriations, 1992 ($ millions). SOURCE: U.S. Department of Energy, 1992.

6). Subsidies flowing into the transportation sector, estimated at between $60 and $300 billion, have been excluded from the scaled mapping. Subsidies to the oil, coal, gas, nuclear, and utility sectors amount to almost $8.5 billion compared with less than $0.5 billion for renewable options.

These types of metabolic mappings can be applied to various sectors of the economy and used at different geographic scales. Figure 9 shows the flow of water through the United States water and wastewater system (Troung, 1993). Very little wastewater is being directly recycled in the system; most reuse is for irrigation (about 930 million gallons per day total or about 2.6 percent of wastewater discharged from treatment facilities, represented by the flow of reclaimed water in Figure 9). In addition, a large amount of water remains unaccounted for or is lost in conveyance (through leaks in pipes, irrigation systems, etc.). The diversion of water for the energy sector almost equals that for agriculture.[8] Other flows through this system have significant environmental impacts. The sludge output is around 5 billion dry tons per year (1988 figure) and the energy inputs for the pumping and treatment of water and wastewater amount to 1 to 2 percent of all electricity consumed in the United States (Truong, 1993). Again, the metabolic, holistic view of the water and wastewater system shows high throughput levels, significant waste generation, and little reuse of resource and waste streams.

These types of analyses are needed for all national systems with critical impacts on the economy. Though the physicist and the engineer often focus on mappings of resource flows, the policy maker needs a larger contextual and historical picture to assess national policies and alternative strategies.

System efficiencies and macroinfrastructures need to be measured across various cultural and social systems, across regions with different cultural and social systems, different resource endowments, and different policy and regulatory regimes. If we are to improve the metabolism of transformational systems over time, such analyses could also be used to explore various future scenarios, showing the results of changes in policies, technologies, consumer preferences, etc. Studies of metabolic processes at various scales and for various resources (energy, materials, capital, labor, etc.) may be our best defenses against the myopia imposed by not thinking in terms of systems. A more sustainable industrial ecology must be built on an analytical ecology that creates a holistic perspective of how society functions.


total federal subsidy for primary sources and end uses of energy, *not including transportation*
uranium enrichment 550m
Price-Anderson Act[a] 3000m
Nuclear
3550m
tax deferrals-working int in oil and gas properties 15m
alt fuel production credit 670m
excess % of depletion 380m
LIHEAP 563m
regulators 92m
Natural Gas
1705m
regulation 215m
LIHEAP, 262m
15m
excess % of depletion 380m
tax deferrals-working int in oil and gas properties
Oil
872m
synthetic fuel sub 72m
regulation 207m
expensing of expl and dev costs
% over cost 265m depletion
Coal
579m
Utilities
Industrial
Transportation
1731m
LIHEAP 137m
power marketing/ REA/Energy Services[b] 1409m
Interest on bonds 185m
?
externalities not borne by drivers (health costs from pollution, reduction of CO_2, security costs, accidents, noise costs) 55-126m
60-300 billion
highway costs not borne by drivers in construction, maintanance, police, and free parking 3000-180000m

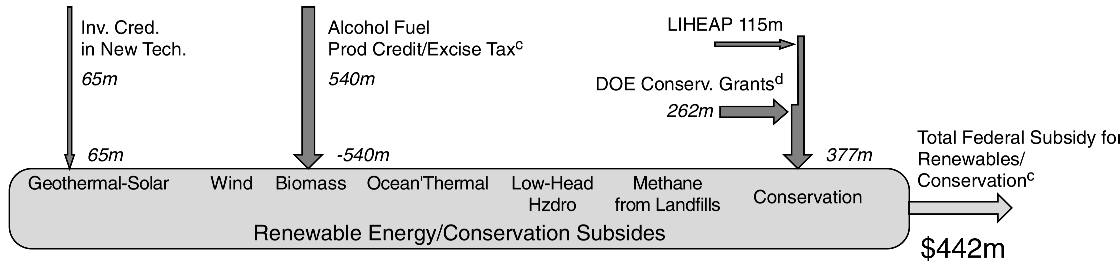


FIGURE 8 Federal tax and direct expenditures 1992, energy sector. All items drawn to scale.

[a]The Price-Anderson Act of 1950 reduces liability as of 1968 to $7 billion in case of a nuclear accident. There are many other nuclear subsidies not included due to the difficulty in quantifying cost, including past fuel enrichment and future decomissioning and waste-storage costs.

[b]The Department of Energy operates 123 hydropower plants at below cost, giving hydro $400 million of this subsidy.

[c]The biomass subsidy is not considered a renewable subsidy. It is actually a production credit for alcohol fuels given to distributors who blend at least 10 percent alcohol with motor fuels. The "gasohol" created from this subsidy is largely petroleum and thus is not a renewable fuel.

[d]Low Income Housing Energy Assistant Program (LIHEAP) provides utility bill and weatherization assistance to 5.8 million low-income households.

SOURCES: Center for Renewable Resource, 1985; U.S. Department of Energy, 1992; World Resources Institute, 1987, 1992. Figure supplied courtesy of David Bassett, U.S. Department of Energy.

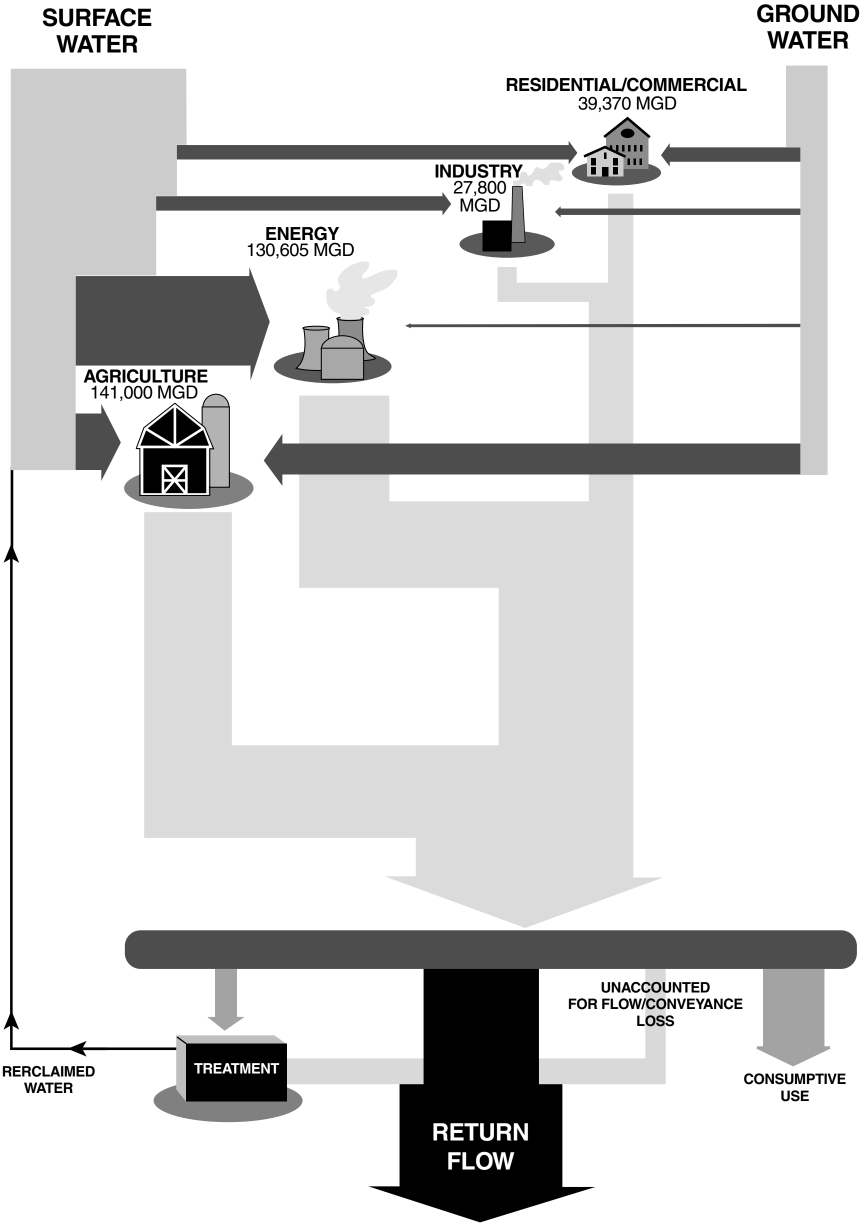


FIGURE 9 The U.S. water and wastewater system. MGD = million gallons per day.
SOURCE: Troung, 1993

ESSAY 3: TECHNOLOGICAL CHOICES

Whether or not it draws on new scientific research, technology is a branch of moral philosophy, not of science.

Paul Goodman, New Reformation

Recently, we witnessed the end of the Cold War. Viewed from the perspective of daily newspapers, it is easy to dismiss this geopolitical event. As Czech President Vaclav Havel recently observed, we may have simply replaced the "communism nightmare" with the "post-communist nightmare." If people only remember our wars and revolutions, then the end of the Cold War may take a prominent place in historical annals. The futurist will note that this occurrence did stimulate a long-needed rethinking of the U.S. government's role in managing the intellectual and policy machinery affecting our science and technology infrastructure. Whether or not our technological prowess helped win the Cold War is a debatable point. However, the ability of the military imperative to shape the technological agenda has now significantly declined.

The past 4 years have seen a new debate on science and technology policy in the United States being carried out in forums, commissions, and publications.[9] Different camps have emerged to do battle for the enormous U.S. federal R&D budget (over $75 billion). These range from the social Darwinists (the best technology will win out), to the neoclassical economists (the market knows best), to the utilitarian moralists (technology for what ends?), to the democratists (who decides?). Such ideological eclecticism is needed, and a well-rounded debate from multiple perspectives will be crucial to move funding away from defense-related technologies. (Over 50 percent of the U.S. R&D budget is still being targeted at military applications.)

Interestingly, other countries in which the military imperative played a far less important role in shaping the technological landscape are also beginning the search for new paradigms and technologies. The Netherlands recently began a large, multiagency program to define and develop technologies critical to sustainable development (Vergragt and Jansen, 1992). This exercise is built on the development of long-term social goals (for energy, shelter, nutrition, clothing, etc.) and the use of "backcasting" exercises to define the required policy paths to achieve these objectives. The Dutch and Danish programs include high levels of public and industry participation in developing both social goals and the technological means and policy measures to reach them.

Internationally, there is an increase in large-scale, structured searches for new paradigms. Some of these projects are being undertaken by governments, though nongovernmental organizations are also becoming more active in this area.[10] Most of these exercises are grounded in the belief that incremental changes in the social, political, and technological infrastructure will prove inadequate in meeting the global challenges posed by rapid population and economic growth over the next 50 years. The old paradigms and ways of doing business have

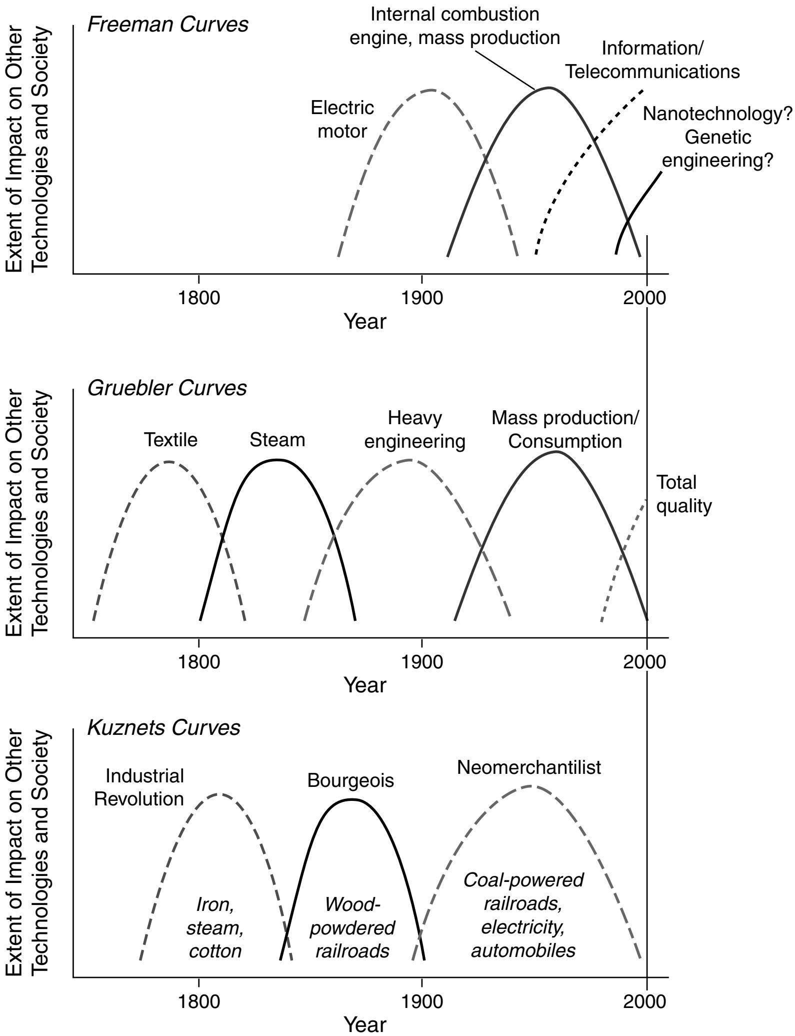


FIGURE 10 Freeman, Gruebler, and Kuznets curves: extent of impact on other technologies and society. SOURCES: Freeman, 1992; Gruebler, 1993; Kuznets, 1953.

simply reached the limits of environmental responsibility, economic efficiency, and political acceptance, and questions are being raised concerning their potential successors.

Of particular interest are what some have termed technoeconomic paradigms—pervasive changes in the technological infrastructure that affect multiple sectors of the economy and the development and application of other technologies (Freeman, 1992). Figure 10 compares a number of attempts to chart such shifts in these paradigms over the past 2 centuries (Freeman, 1992; Gruebler, 1993; Kuznets, 1953). Interestingly, there is a high degree of agreement on the length and character of the last great wave, which included "Fordist" mass production techniques, the internal combustion engine, and petrochemicals. One could argue that this paradigm was extremely pernicious from an environmental standpoint, and much of the organizational apparatus of environmental protection continues to deal with the intended, or unintended, side effects of this paradigm. To a large degree, industrial ecology is a response to the ecological dysfunction embedded in this model.

Three points can be made about such dramatic shifts. First, these paradigms often become dominant for several decades, influencing the range of technological options and the character and rate of innovation. Second, much of the commitment--to technologies, the institutions that support them, and the capital that enables them--is focused on past and present paradigms. Third, the risks involved in the explorations of new paradigms are probably too high for most industries to bear without government cooperation. Governments need to explore the outer envelopes of these emerging and new trajectories, because the "lock in" of technologies, and their associated social and financial infrastructures, may occur very early and lead toward unsustainable development paths. This must be done when the social change potential is high and before significant human, capital, and intellectual resources have been committed by the public or private sector (Figure 11).

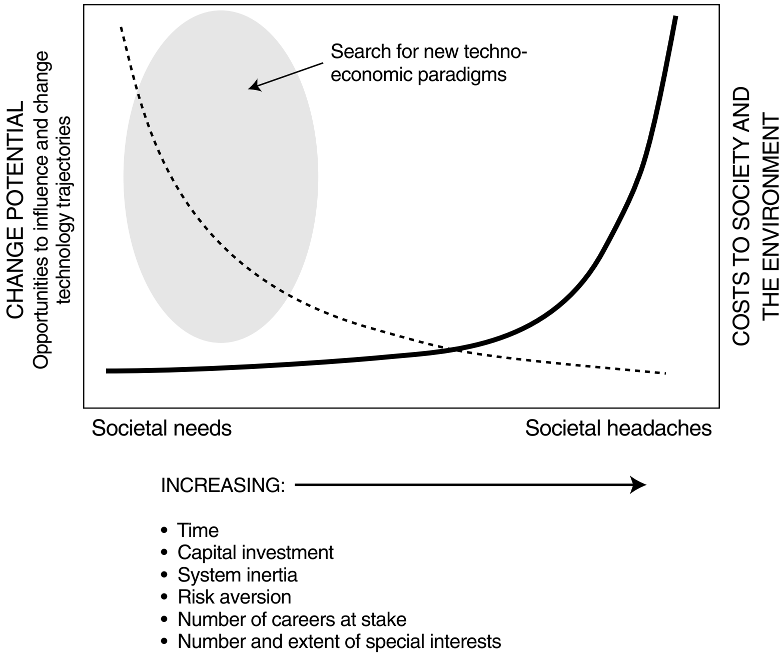


FIGURE 11 Changing potential: opportunities to influence and change technology and trajectories. SOURCE: Adapted from a graph by Bassett, 1990.

Though the historical shifts in these paradigms have been explored quite extensively, far less has been done to try to define their potential successors. Freeman (1992) has argued that the existing information and communications technology paradigm could be adapted for sustainable development but will ultimately prove insufficient and a new paradigm will be needed.

Where would searches for such paradigms begin?[11] Attempts to characterize the status of next-wave technologies can be summarized as follows: The operating principles (cause-and-effect relationships) of the next-wave technologies have already been identified, most of the applications of those principles to inventions have already been conceived of, many of the basic innovations are already being worked on in laboratories, half of the basic innovations have begun development, but very few of the innovations of the next long wave are available commercially (Graham and Senge, 1980). Such a characterization still leaves considerable uncertainty, because many generic, precompetitive technologies meet these criteria. One can deal with this uncertainty by developing several possible scenarios, in essence defining a scenario space in which the future may play itself out. These descriptive scenarios would be conditional if-then explorations of the future to assess the impact of particular technoeconomic paradigms on the industrial sector and industrial ecology itself over the next 40 to 50 years.

For instance, the miniaturization of mechanics may have as profound an impact on industry and society as the miniaturization of electronics. A recent National Science Foundation document noted that microdynamics may well create profound changes in medicine, science, communications, and industry (National Science Foundation, 1988). Several nations, including the Netherlands and Japan, have identified microdynamic systems as a critical area of research in the coming decade (Brendley and Steeb, 1993).[12] At one level, microdynamic sensor systems will offer much better control of the flows of energy and materials used in industrial processes. However, the impacts on economic and industrial systems could go far beyond that. The ability to manufacture at a molecular, or eventually an atomic, scale could radically reduce industrial throughputs of energy and materials, generation of wastes, and design times for products, fundamentally altering the system of flows and structural and organizational dynamics on which industry's ecology is presently built. The microscale mechanics scenario could interact in interesting ways with the existing information and communications technoeconomic paradigm, accelerating the development of extremely small-scale intelligent assembly systems and smart sensors that could have large intra- and intersectoral impacts.

If we can anticipate such new trajectories, could we then chose those with the greatest chance of leading us down a sustainability path? Few attempts have been made to map multiple technology trajectories and their complex interactions. (An interesting discussion can be found in Schot et al., 1993.) There have been even fewer attempts to do this in a normative context where the endpoints of such trajectories would converge on some set of long-range, socially defined and agreed-upon goals. However, the idea that a key group of critical technologies exists somewhere that needs to be discovered and exploited has been a key motivating factor in the development of so-called critical technology lists. (See Kenzo, 1991.) Though many of these list have proved too generic to be of use for policymaking, the idea that one can identify a priori technologies that may be critical to economic growth, human well-being, sustainable development, or global competitiveness remains a seductive challenge to policy and decision-makers.

The most important point from this brief exploration is this: Industrial ecology must encompass a forward-looking search for next-wave technologies. In short, industrial ecology must be defined within the context of the wider sociocultural future of communities, cities, regions, states, and nations. What are the implications of an industrial ecology embedded in a hydrogen economy? Will such an economy abandon petroleum-based chemical synthesis, be built on microscale processes or advanced materials, and support a knowledge-based rather than commodity-based commerce? It is unlikely that industry alone can answer these questions, but industry and government should begin to explore and facilitate the broader public discussion surrounding our long-term goals and the technological paths to these objectives.

Johnathan Swift once noted that "vision is the art of seeing the invisible." The search for the invisible will not begin or end in the firm, in the office of government bureaucrats, or at late-night town meetings. History has provided us with an opportunity to craft a new technology policy, but this policy will require a rare combination of foresight, innovation, political will, and public consent to search for and collectively choose new technological paradigms.

POSTSCRIPT

Maurice Strong (1994), organizer of the 1992 Earth Summit recently commented that

> for all the good things that our political leaders are saying these days about sustainable development, the economic, fiscal, and sectoral policies of government by and large continue to provide incentives and subsidies for environmentally unsound behavior. Ultimately, a sustainable future will require us to move from political rhetoric to fundamental changes in the way we measure humanity's progress, use our limited natural resources, and evaluate our technological choices. Business and government must make this move together to realize the potential of an [environmentally sound] industrial ecology and a sustainable political economy.

NOTES

1. A 1992 Environmental Protection Agency (EPA)-sponsored study by the World Resources Institute focused on some of the institutional learning challenges facing the government and concluded that there was a significant risk that "the great strides made by private institutions during the next 30 years will probably not be matched by public institutions." See: Challenges Ahead

for the Environmental Protection Agency in the 21st Century, prepared by the World Resources Institute in Cooperation with the U.S. Environmental Protection Agency. Document located at http://www.epa.gov/docs/futures/mega/challenge.txt.html.

2. The rapid globalization of the world's economy may ultimately make regions and cities more important than nations as centers of commerce and economic power. By the year 2000, there will be 19 cities with populations over 20 million people. For this reason, regional and urban economies impacting the flows of energy and materials may become more important as a unit of analysis than nations themselves.
3. Frosch (1996) discusses industrial and environmental history passing through similar phases from a state when "environmental impacts were generally regarded as external to the industry" to a state of greater internalization of effects when "manufacturing combines cost minimization with low or zero production of wastes."
4. Natural capital can include the biological and mineral resources of a country, such as water, forests, wetlands, protected ecosystems, air, soils, subsoil minerals, and all living resources. Commercial natural resources (such as fossil fuels and agricultural lands) are often excluded because they are normally addressed in annual economic accounts.
5. Early attempts to develop resource accounting methods within the U.S. Bureau of Economic Analysis (BEA) were ended abruptly in the early 1980s after the publication of only one paper. Recently, BEA has begun a new program on natural resource accounting (Bureau of Economic Analysis, 1993). A prototype green GDP was unveiled by the U.S. Department of Commerce on Earth Day 1994.
6. A recent conference on urban metabolism in Kobe, Japan, addressed some of the strengths and limitations of the metabolic metaphor. Though the concept of metabolism focuses our attention on highly complex systems essential to life, it does not address the social, ethnic, linguistic, and class differences underlying our cultures and human values. As a metaphor it is essentially descriptive with little culturally relevant normative power (Ness, 1994).
7. The mappings of the U.S. Energy sector presented in this paper were developed by the following people: energy (David Bassett, U.S. Department of Energy), research and development expenditures (Michael Manning, EPA), and subsidies (Michael Brylawski, Stanford University).
8. Though this has yet to pose serious problems in the United States, use conflicts are already occurring in countries such as China where significant amounts of water are being diverted from irrigation to cool large, coal-fired power plants.
9. The flavor of this debate can be captured by looking at the following documents: the series of publications by the Carnegie Commission on Science, Technology and Government; the debate in the Harvard Business Review (1992) surrounding an article by Lewis Branscomb (1992) on whether America needs an industrial policy; and a 1992 report by the Office of Technology Assessment called "Technology and the American Economic Transition: Choices for the Future."
10. One of the best examples of a nongovernmental organization project looking for new paradigms is the 2050 Project being undertaken by the World Resources Institute, the Brookings Institution, and the Santa Fe Institute.
11. An unorthodox but often fruitful place to search for new paradigms is in utopian literature. Interestingly, visions of possible future worlds built on new social, political, and technological paradigms tend to proliferate every 50 to 60 years, during the stagnation phase of long-term Kondratieff cycles (Kiser and Kriss, 1987)
12. The United States lags behind a number of nations in investments in microdynamics systems research and development. Japan is presently spending \$150 million to \$200 million per year; the Netherlands, \$100 million; Germany, \$70 million to \$100 million; and the United States, \$15 million to \$20 million (Brendley and Steeb, 1993).

REFERENCES

Ackoff, R. L. 1981. Creating the Corporate Future: Plan or Be Planned For. New York: Wiley.

Allen, T. F. H., and T. B. Starr. 1982. Hierarchy: Perspectives for Ecological Complexity. Chicago: The University of Chicago Press.

Alfsen, K. H. 1987. Natural Resource Accounting and Analysis: The Norwegian Experience 1978-1986. Oslo, Norway: Central Bureau of Statistics.

Ausubel, J. H., R. Herman, and S. Ardenkani. 1989. Dematerialization. in Technology and Environment, J. H. Ausubel and H. E. Sladovich, eds. Pp. 333–347 in Technology and Environment. Washington, D.C.: National Academy Press.

Bassett, D. , U.S. Department of Energy. Personal communication.

Blair, P., Office of Technology Assessment. 1991. Personal communication.

Branscomb, L. 1992. Does America need a technology policy? Harvard Business Review 70(2):24–31.

Bureau of Economic Analysis (BEA). 1993. Natural Resource and Environmental Accounts. Washington, D.C.: BEA.

Brendley, K. W., and R. Steeb. 1993. Military Applications of Microelectromechanical Systems. Santa Monica, Calif.: Rand.

Center for Renewable Resources (CRR). 1985. Hidden Costs of Energy. Washington, D.C.: CRR.

Colby, M. E. 1990. Environmental Management in Development: The Evolution of Paradigms. World Bank Discussion Paper 80. Washington, D.C.: World Bank.

Folke, C., and T. Kaberger. 1991. Recent trends in linking the natural environment and the economy. Pp. 274–297 in Linking the Natural Environment and the Economy: Essays from the Eco-Eco Group. Dordrecht: Kluwer Academic Press.

Freese, L. 1985. Social Traps and Dilemmas: Where social psychology meets human ecology. Paper presented at the American Sociological Association, Washington State University, Pullman, Wash.

Freeman, C. 1992. The Economics of Hope: Essays on Technical Change, Economic Growth and the Environment. London: Pinter.

Frosch, R. A. 1996. Toward the end of waste: Reflections on a new ecology of industry. Pp. 157–167 in Technological Trajectories and the Human Environment. J. H. Ausubel and H. D. Langford, eds. Washington, D.C.: National Academy Press.

Georgescu-Roegen, N. 1979. Comments on Daly and Stiglitz. Pp. 95–105 in K. Smith, ed., Scarcity and Growth Reconsidered. Baltimore: Johns Hopkins University Press.

Graham, A., and P. Senge. 1980. A long-wave hypothesis of innovation. Technological Forecasting and Social Change 17:283–311.

Gruebler, A. 1997. Time for a change: On patterns of diffusion of innovation. Pp. 14–32 in Technological Trajectories and the Human Environment. J. H. Ausubel and H. D. Langford, eds. Washington, D.C.: National Academy Press.

Harvard Business Review. 1992. Debate: Technology policy: Is America on the right track? Harvard Business Review 70(3):140–156.

Holling, C. S. 1992. Sustainability: The Cross-Scale Dimension. Paper presented at a conference on Definition and Measurement of Sustainability: Biophysical Foundations, World Bank, Washington, D.C., June 22–25.

Hueting, R., P. Bosch, and B. de Boer. 1991. Methodology for the Calculation of Sustainable National Income. Internal Paper 12.130-91-E10. Voorburg, Holland: Netherlands Central Bureau of Statistics.

Jaenicke, M., H. Moench, R. Ranneberg, and U. Simonis. 1989. Structural change and environmental impact: Empirical evidence on thirty-one countries in East and West. Environmental Monitoring and Assessment 12:99–114.

Kenzo, G. J. 1991. Critical Technology Lists: A Comparison of Published Lists and Legislative Proposals. Report for Congress, 91-367 SPR. Washington, D.C.: Congressional Research Service.

Kiser, E., and D. Kriss. 1987. Changes in the core of the world-system and the production of utopian literature in Great Britain and the United States, 1883–1975. American Sociological Review 52.

Kuznets, S. 1953. Economic Change. New York: Norton.

MacCready, P., Aerovisionment. 1991. Personal communication.

National Science Foundation. 1989. Small Machines, Large Opportunities: A Report on the Emerging Field of Microdynamics. Washington, D.C.: National Science Foundation.

Ness, G. 1994. Pursuing the metabolic metaphor. Human Dimensions Quarterly (University of Michigan) 1:11–12.

Schot, J., B. Elzen, and R. Hoogma. 1993. Strategies for shifting technological trajectories. Paper presented at the international workshop, The Car and its Environments, Trondheim, Norway, May 5–7.

Shafik, N. 1994. Economic development and environmental quality: Patterns of change. Unpublished paper. Washington, D.C.: World Bank.

Solow, R. 1974. The economics of resources or the resources of economics. Journal of the American Economics Association 64:1–14.

Strong, M. F. 1994. In the trenches: Building on Rio's blueprint for a sustainable world. Remarks at the annual meeting of the Environmental Business Council of New England, Boston, May 4.

Truong, T. 1993. Emerging Issues Related to Water Infrastructure and Legislation. Future Studies Unit Working Paper. Washington, D.C.: Environmental Protection Agency.

TRW/U.S. Energy Research and Development Administration (USERDA). 1977. Road Vehicles. Washington, D.C.: TRW/USERDA.

U.S. Bureau of Mines. 1991. The New Materials Society: Material Shifts in the New Society, Vol. 3. Washington, D.C.: Bureau of Mines.

U.S. Congress, Office of Technology Assessment. 1988. Technology and the American Economic Transition: Choices for the Future. Washington, D.C.: U.S. Government Printing Office.

U.S. Council on Environmental Quality. 1989. Environmental Trends. Executive Office of the U.S. President. Washington, D.C.: U.S. Government Printing Office.

U.S. Council on Environmental Quality. 1994. Environmental Trends. Washington, D.C.: U.S. Government Printing Office.

U.S. Department of Energy. 1990. Annual Energy Outlook 1990. Washington, D.C.: U.S. Government Printing Office.

U.S. Department of Energy. 1991. National Energy Strategy: Powerful Ideas for America. Washington, D.C.: U.S. Government Printing Office.

U.S. Department of Energy. 1992. Federal Energy Subsidies: Direct and Indirect Interventions in Energy Markets. Energy Information Administration. Washington, D.C.: U.S. Government Printing Office.

U.S. Department of Energy. 1996. Annual Energy Outlook 1996. Washington, D.C.: U.S. Government Printing Office.

U.S. Environmental Protection Agency (EPA). 1989. National Air Pollution Emission Estimates, 1940–1987. Washington, D.C.: U.S. Government Printing Office.

Vergragt, P., and L. Jansen. 1992. Sustainable Technological Development: The Making of a Dutch Long-Term Oriented Technology Program. Paper presented for 4S-EAAST Conference, Gotheburg, Sweden, August.

Weinberg, M., G. Eyring, J. Raguso, and D. Jensen. 1994. Industrial ecology: The role of the government. Pp. 123–133 in The Greening of Industrial Ecosystems, B. R. Allenby and D. J. Richards, eds. Washington, D.C.: National Academy Press.

World Resources Institute (WRI). 1987. Money to Burn? The High Cost of Energy Subsidies. Washington, D.C.: WRI.

World Resources Institute (WRI). 1992. The Going Rate: What It Really Costs to Drive. Washington, D.C. : WRI.

The Industrial Green Game. 1997. Pp. 73–90.
Washington, DC: National Academy Press.

Energetic Concepts Drawn from Electricity Production and Consumption

GLYN ENGLAND AND DAVID R. COPE

Industrial ecology is a complex, almost labyrinthine subject. It is undoubtedly true that "everything affects everything else" (Smart, 1992), but this hardly makes for easy exposition. Furthermore, of all the various goods, services, and systems that can be examined from an industrial ecology perspective, energy is probably the most fundamental and intricate in its characteristics.

First, this concepts paper examines electricity alone as an energy source and covers the generation of electricity from different fuels or other sources of input energy for the conversion process. The important question of the appropriate energy source for particular end purposes (such as, whether it is better to use gas rather than electricity for space heating, or electricity rather than gasoline or diesel fuel for motive power) will not be considered here.[1] Excluded also is detailed discussion of many potential energy sources and delivery systems, including renewables, highly speculative high-tech systems (e.g., microwave energy from space or ocean thermal energy conversion), and the hydrogen energy economy.[2]

Second, industrial ecology is illustrated through use of the electricity sector of the United Kingdom: England, Wales, Scotland, and Northern Ireland. Some European countries have followed different paths in the evolution of their electricity generation, paths that in some cases could be considered more in keeping with the industrial ecology concept, particularly in the extent to which they already use significant amounts of combined heat and power (usually called cogeneration in North America).[3]

Third, this paper focuses on general energy and electricity use, not so much at the national level but at the level of a single building, a single production plant, or small groupings of these. This approach is taken because if the application of industrial ecology is to become widespread, it is likely to emerge from specific initiatives at this level rather than from any broad, national policies. This paper also examines how well the industrial ecosystems of electric utilities are doing and what barriers prevent better performance.

INDUSTRIAL ECOLOGY: ANALYSIS AND PRESCRIPTION

One definition of industrial ecology is "the network of all industrial processes as they may interact with each other and live off each other, not only in the economic sense but also in the sense of the direct use of each other's energy and material wastes" (Ausubel, 1992).

Although most applications of industrial ecology are likely to be found in the manufacturing sector, it is important to consider the links in the entire production and consumption process, from the extraction of raw materials to their final use by consumers, including the transport flows involved. The use of the term industrial ecology can be misleading unless it is understood as embracing "industrial society" in all its dimensions. With electricity generation, in particular, there may be significant possibilities in linking industrial production to use and by consumers.

At one level, the study of the relationships that exist or could exist among industrial processes should be value free and thus provide a powerful analytical framework for examining the economics of production, consumption, and the processes involved (Tibbs, 1992). An analysis of the outcomes that might be realized if the barriers to better performance by electric utilities were removed should include the value judgments and the vision on which these outcomes are based.

It is axiomatic that the aim of industrial activity is to satisfy human wants. Superimposed on this are some inchoate value judgments emerging from sustainable development. One is the importance of minimizing the use of primary, nonrenewable resources and, in particular, of increasing the energy productivity of resources. Some consider this is a goal in its own right. This view maintains that there is an obligation to conserve resources for the benefit of future generations. This is a complex issue. The emphasis however, is on the need to optimize resource use, within economic constraints, so as to minimize any unavoidable associated environmental consequences.

Such optimization is likely, given the present characteristics of market economies, to be realized first at the level of the individual firm. Considerable resource use will continue to occur, even after it has been optimized within firms. The industrial ecology assessment can be used to minimize waste at all stages of production and use. Waste, in this context, is the less-than-efficient use of the resources themselves as well as any physical waste that arises in production, movement of raw materials and products, and end use.

The practical application of industrial ecology therefore is to improve efficiency, often on a scale larger than individual firms. This larger system can be defined as a group of interrelated industrial enterprises or a geographic entity, such as an industrial estate, a science park, a city, or a region. Geographical propinquity, although not required for achieving efficiency improvements at the larger economic scale, facilitates the process in many cases by reducing the need for transporting people and materials and encouraging like-mindedness among those whose initiative is required. Like-mindedness may arise most readily from social interaction stemming from living or working close to potential collaborators, though electronic communication is already reducing the need for physical proximity in many instances.

This spatial aspect of industrial ecology has implications for land-use policy and environmental regulations. There is probably a limit to the extent to which living functions can coexist alongside producing functions. Due regard for environmental improvement may reduce the direct environmental penalties of living close to industrial activity, but a preference for some degree of segregation will probably remain.[4]

Environmental regulations should not needlessly constrain the potential for achieving the necessary systemic interlinkages, as controls on the movement of waste do. Waste is the intermediate material of the industrial-ecological nexus. In the United Kingdom and other parts of Europe, problems have arisen because the waste outputs of one process that are a potential raw material for another process have been classified as waste requiring handling procedures and documentation that may make its subsequent use uneconomical.

WHY ENERGY IS SPECIAL

Energy has a special place in industrial ecology for at least two reasons. First, it is an essential ingredient of almost all industrial and commercial processes and is used in large measure directly by consumers. Very few people do not benefit from processes that are pervaded by human-manufactured energy.

The boundaries of industrial ecology do not stop at the factory gate; linking industry and its products with other areas of human activity is a key consideration. Table 1 shows the energy and electricity consumption of different sectors in the United Kingdom and the importance of electricity compared with other final uses of energy sources. The picture is broadly similar in other European countries.

The second consideration is that the original extraction or harvesting of the energy source, to usable form conversion, supply to consumers, and end use usually all have significant environmental consequences. Table 2 shows contributions to national air emissions from energy use and electricity production in the United Kingdom. This pattern is not necessarily replicated in other European countries, mainly because the United Kingdom currently relies heavily on coal for electricity generation.

TABLE 1 Energy and Electricity Consumption by Final-Use Sectors, United Kingdom, 1992

Sector	Amount ($\times 10^{18}$ joules)	Percentage	Amount ($\times 10^{18}$ joules)	Percentage	Electricity as percentage of all energy
Transport	2.058	32.5	0.019	1.9	1.0
Domestic	1.840	29.0	0.358	35.1	19.5
Industry and agriculture	1.642	26.9	0.377	37.0	23.0
Commerce	0.445	7.0	0.187	18.4	42.1
Public administration	0.361	5.7	0.078	7.6	21.5
Total	6.346	100.0	1.019	100.0	16.1

NOTE: From an industrial ecology perspective, it would be more illuminating if transport energy could be allocated to the various purposes for which it is used (e.g., transport of goods, use of motor vehicles in the course of employment, etc.). This is because transport is usually not a goal in its own right but a means to achieving other goals. Routine United Kingdom statistics do not permit such a reallocation. There are also classification problems. For example, should journey-to-work energy use be allocated to industry, public administration, commerce, etc., or is it a domestic use?

Similarly, some proportion at least of commercial and administrative use of energy supports industrial production or domestic consumption. This proportion ought also, ideally, to be reallocated to one or the other of these sectors.

SOURCE: Department of Trade and Industry, 1994.

TABLE 2 Emissions Originating from Energy Use and Electricity Production, Percentage by Substance, United Kingdom, 1992[a]

Substance	From Energy Use	From Electricity Generation
Sulfur dioxide	99	71
Nitrogen oxides	97	26
Carbon monoxide	97	1
Black smoke[b]	88	5
Methane	37	—
Volatile organic compounds	34	—
Carbon dioxide	97	33

[a]This table lists only certain emissions to air. There are also aspects such as the waste from coal and uranium mining, spills and leakages from oil and gas production, thermal and other water discharges from electricity generation, visual intrusion and the proportion of human-originating radioactive dosage arising from the civilian nuclear electric (and coal-burning) fuel chains.

[b]Black smoke is fine carbonaceous particulate matter.

SOURCE: Department of Trade and Industry, 1994.

WHEN THE ENERGY CHAIN BEGINS WITH END USE

In examining electricity utilities, it is useful first to set them in the context of the energy chain, from the supply of the original heat or motive-power source used to generate the electricity through to the end use of the electricity generated. In doing this, industrial ecology suggests that the end use of the electricity generated is the appropriate starting point, and that one should then work backward to the power plant and the original energy source. The reasoning is essentially heuristic: This approach focuses attention on the fact that the aim of the entire system is to supply useful energy at the point of use, not to generate the maximum number of kilowatt-hours, to mine the maximum amount of coal or uranium, or extract the maximum amount of oil or gas.

Electricity utilities are located in the middle of this chain. With some integrated utilities, control of virtually all the links, apart from the final consumption, is within the ambit of one enterprise. They have their own dedicated fuel sources—mines or gasfields, for example—and generate, transmit, and distribute their electricity. (Some are also involved in supplying other energy sources.) A few sell electric appliances and therefore can influence final-use considerations. Other utility enterprises may comprise only one link—a bulk generator or a distributor that purchases its power supplies from other enterprises. The United Kingdom probably has the most complex electricity-supply chain in the world. (See Appendix 1.)

How much an individual enterprise controls the various links in the chain will almost inevitably affect the opportunities for cooperation and optimization. In a perfect market system in which the economic drivers are present, optimum coordination should occur whether one large enterprise or a plurality of smaller enterprises is involved. In reality, however, the prospects for cooperation are more favorable when elements of a supply system are controlled by one enterprise, even though the individual links may be treated as independent profit centers.

AN END-USE CASE STUDY: ENERGY IN BUILDINGS

The ultimate aims of energy use are to live comfortably, to produce goods for consumption, and to be able to move about. In the United Kingdom, the first two activities require buildings and building services that account for more than 40 percent of the total primary energy consumption, most of which goes for space heating (Littler and Thomas, 1984). Air conditioning is mainly confined to the commercial sector, where its rapid penetration has been a key factor in the sector's increasing electricity consumption.

Although some general principles relating to orientation, insulation, and fenestration have been developed, buildings are specific to location and local climate. There are now many well-documented examples of domestic, commercial, and public buildings that use substantially less energy than do more traditional structures. The Energy Efficiency Office of the U.K. government claims that buildings that are cost effective can reduce energy use by at least 50 percent compared with conventional designs.

However, there are a number of barriers to more widespread energy reduction through building design and energy management.

Longevity of Building Stock

In the United Kingdom, building lifetime is frequently taken as 60 years for homes and between 30 and 70 years for offices. Therefore, applying new techniques to new buildings alone, necessary though it is, produces only a slow overall improvement in energy efficiency. For more significant improvements, the refurbishment and upgrading of older buildings is a priority. A study of a typical early-1970s Bristol office building (concrete construction with sealed bronze-tinted glazing and an air conditioning system approaching the end of its life) concluded that passive principles could be applied even in such unpromising circumstances (Bunn, 1993). It also concluded that a life-cycle cost analysis reinforced the financial argument for avoiding air conditioning. The refurbishment did not proceed, however, due to other barriers.

Like many other commercial buildings, the building in Bristol had an owner and several long-term tenants. The interests of these parties are often not identical and inflexibilities in the market prevent the appropriate allocation of costs between the parties. Owners are reluctant to undertake capital investment that would reduce energy consumption unless the investment can be recouped from rent increases or a higher price when the property is sold. Tenants are similarly reluctant to invest because they will not own any of installed equipment and will not be able to realize their investment if they move before its payback period. The lack of commitment that occurred in this case study is duplicated frequently elsewhere.

Lack of Information

A potential home owner often has inadequate information for reaching a rational decision when balancing first costs and operating costs of energy-using equipment and energy-conservation activities. In the United Kingdom, the National Home Energy Rating Scheme provides a measure, on a scale of 0 to 10, of the energy efficiency of domestic dwellings. It takes into account the design and construction of the property, the efficiency of the heating system and its controls, the fuel used, the lighting system, and appliances. The scheme is administered by a nonprofit organization that registers organizations such as local government departments, private consultancies, home-building companies, and others as authorities competent to offer official ratings.

The scheme has several aims. In particular, it is hoped that a high rating on the scale will be reflected in the market price of a property. This may encourage current owners to invest in energy conservation strategies, secure in the knowledge that they will achieve a return on their investment if they sell as well as incur lower costs from reduced energy consumption.

In practice, the scheme has enjoyed a higher rate of adoption by institutional providers of domestic dwellings than from owner-occupiers.[5] These institutional providers have responded to various government incentives to consider the energy efficiency of their dwelling stock and through their response, hundreds of thousands of units in this housing sector have been classified. However, most of the 22 million dwelling units in the United Kingdom are owner occupied, and the adoption of energy-saving measures in this sector has not been encouraging.

Major new-house building enterprises have joined the scheme, but the hope that families moving into new homes or taking the first step of home ownership would regard an energy rating as a major consideration in their home purchase choice has not been realized. One reason is the limited budget to publicize the existence of the rating. Another factor is that home-running costs tend to be heavily discounted against first-purchase costs.

Some commentators have suggested that energy efficiency ratings should be made compulsory and that ratings should accompany the legal documents proving ownership. Another option would be for mortgage providers to make a rating a requirement for a loan, although they have no incentive to concern themselves with the energy efficiency of mortgaged properties. Such coercion is likely to be highly unpopular politically with homeowners, a key section of the U.K. electorate. If a high energy-efficiency rating was reflected in the sale price home owners might voluntarily seek to have their dwellings related, but this remains an elusive goal.

Savings Guarantees

Even when convinced of the theoretical attractiveness of an investment, potential investors need to be confident that calculated savings will actually materialize. Although there are some examples of very short payback periods, investments frequently materialize only after a considerable number of years have passed. Investors can be nervous that their investment risk may be adversely affected by regulatory, fiscal, or other fluctuations or rule changes. Capital tax allowances can be critical for industrial buildings, and property tax and mortgage interest allowances can be critical for dwellings. Such barriers primarily fall to government to remove.

The broad message is that because buildings have such diverse characteristics, there are few simple, generally applicable approaches. A growing number of well-documented case studies, however, can provide both inspiration and guidance. The bottom line is that although energy saving in buildings is often not considered as glamorous as the construction and operation of major projects for energy production or conversion, studies of novel options and lessons from prototypes can lead to innovations with widespread applicability. Action on energy saving is fundamental to and implicit in applying industrial ecology.

Improving energy use in buildings is a challenge to electricity utilities. In the United Kingdom, particularly in the residential sector, space heating is dominated by a competing energy source: direct use of natural gas. Thus, electricity companies might be able to increase market share while, through involvement in energy conservation schemes, contributing to an overall reduction in energy consumption.

ENERGY PRODUCTION: WORST-CASE MODEL

Whatever the potential opportunities from end-use energy conservation, the focus of a utility's concern will nevertheless probably continue to be on the generation link in the electricity chain. The ideal generation process would involve no capital investment, and electricity would spring from it with no associated emissions or by-products.

Reality is somewhat different. In applying industrial ecology as it relates to the generation process, it is useful to consider a worst-case model. The worst case is defined for the purposes of this paper as the most challenging form of new power station that it would be possible to construct in the United Kingdom or other European countries, given existing environmental and other regulations. The characteristics of such a power station are given in Figure 1. In reality, it is highly unlikely that such a station would ever again be constructed, certainly not in the United Kingdom and probably not within the European Union. This statement is, in itself, a measure of how much industrial ecological or more general environmental concern has already become incorporated into economic decision making. Nevertheless, the worst case provides an environmental benchmark against which current developments and future intentions can be measured.

Such a station can be conceptualized as a 500-megawatt conventional pulverized-fuel coal-fired plant. It would be equipped with limestone-gypsum flue gas desulfurization (achieving 95-percent desulfurization) and low nitrous oxides burners, reducing unconstrained emissions by 40 percent. These requirements exist under 1988 European regulations for new-generation plants. The station would have direct or indirect river-water cooling, and its conversion efficiency would be assumed to be 35 percent. Because of the characteristics of the plant, it would almost certainly be located on a site already used for electricity generation or other industrial purposes, situated well away from residential areas, particularly growing, sought-after areas.

The challenge presented by such a station is fourfold and is encapsulated in Figure 1, which details the annual throughputs that together comprise the worst case. First, there are the considerable solid inputs (over 1 million tonnes of coal and the limestone for desulfurization). Then there are the solid by-products of the coal and the desulfurization process. Next, there is the discharge of reject heat,

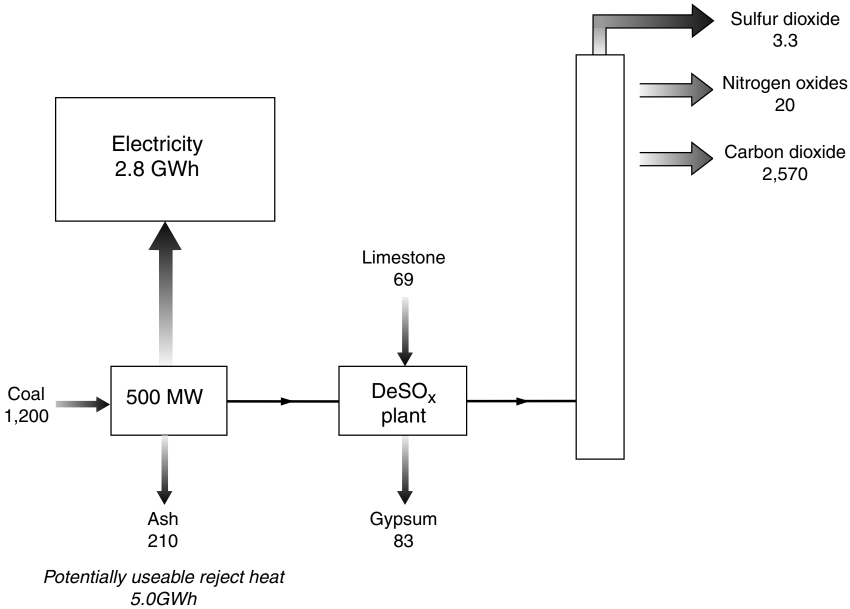


FIGURE 1 Conceptual worst case. Quantities are in tonnes (or 10^3 kilograms). Assumes station uses average European thermal coal (24 gigajoules per tonne, 17 percent ash and, 1.5 percent sulfur) and operates at 35 percent efficiency with 65 percent annual load factor. GWh = gigawatt hours; MW = megawatt; DeSo$_x$ = desulfurization.

usually in cooling water. Water throughput is not included in the figure because this is largely unchanged in the cooling process, although some is lost by evaporation. Finally, there are the remaining gaseous emissions: some sulfur dioxide, nitrous oxides, and carbon dioxide.

ENERGY PRODUCTION IMPROVEMENTS

In the United Kingdom, the most recent response to this challenge has been a switch from coal-fired generation to gas generation, which comes as close as is possible to the generation scheme mentioned above. This fuel change has happened very rapidly, largely because nonmarket constraints have been removed, particularly an archaic European Community regulation that prevented the use of gas for electricity generation. Utilities' responses to environmental requirements have also been a driving force.

The use of gas removes, at a stroke, any need for concern with solid waste streams, such as spent flue gas desulfurizer (FGD) sorbents or ash.[6] Emissions to air, including any leakage of methane that might occur in the delivery of the gas fuel from gas field to power plant are minimized partly because of the innate characteristics of the gas and partly because the use of combined-cycle technology offers considerably higher thermal efficiency and lower emissions per kilowatt-hour generated.

The higher conversion efficiency also means that there is less reject heat per kilowatt-hour. Nevertheless, an industrial ecology consideration is whether even the smaller reject heat stream could be put to good use. In several cases, combined heat and power (cogeneration) schemes, mainly for industrial use of the heat, have been developed to exploit this possibility. One constraint on maximizing the use of reject heat streams from large-scale, gas-fired, combined-cycle plants for nonindustrial purposes is that even such benign generation systems are not generally regarded by U.K. citizens as desirable neighbors in residential areas.

A nonenvironmental consideration created by switching to gas is the question of future availability of gas supplies, which has commercial and possibly national strategic ramifications. Availability is also relevant to the question of timing regarding the development of new, environmentally acceptable, generation technologies to replace gas when it eventually becomes uneconomic. At present, however, there is little concern about imminent supply shortages and, indeed, considerable discussion of the way in which the gas "bubble" is turning into a gas "sausage," possibly of prodigious length. Eventually, when this sausage is fully consumed, the next course of the meal may be much less palatable in terms of industrial ecology considerations.

If electricity generation becomes dependent on "clean coal" technology, even the best of today's development (demonstration) technologies, such as coal-gasification combined cycle, will produce significant amounts of solid waste. This waste can be more difficult to use in secondary markets than that from conventional coal-fired plants. In addition the gaseous emissions of these so-called clean technologies are dirtier than that of natural-gas-fueled systems.

Nuclear fission may fill the void left by diminishing economic supplies of gas. In this scenario, it is difficult to think that public apprehension about the technology, although currently declining from a post-Chernobyl high, will easily reach a point where the geographical proximity often associated in the industrial ecology context would be reconcilable with nuclear-powered sources. Nuclear power, at least in the United Kingdom, shares this constraint with some other generation options (particularly waste combustion) that otherwise fit neatly into an industrial ecology perspective. Nuclear power and other resisted technologies cannot necessarily escape criticism by relocating to remote areas. Even if this were economically viable, these are invariably regions of valued landscapes and ecosystems where electricity generation facilities are also viewed with disfavor by powerful interests.

WASTE INTO ELECTRICITY

Household, commercial, industrial, and agricultural waste of various forms may lend themselves to combustion in electricity-generating plants. Although the principle approach to greener industrial ecosystems might be to minimize the creation of such waste streams in the first place, they are likely to be a permanent feature of advanced industrial societies. In addition, recognition is growing that for some fractions of the waste stream it makes more sense to use the embodied energy through combustion than through complex recycling procedures.

Constraints on the usual first-resort strategy of using such waste as landfill mean that the economic attractiveness of incineration, usually with associated electricity generation, has been growing in the United Kingdom. The economic attractiveness of burning waste has been made more attractive by government intervention in the market. Two incentives have been introduced. The first is a direct subsidy to non-fossil-fuel electricity generation in which waste fuels have been classified as nonfossil even though, as is the case with most plastics, they originally are derived from fossil sources. The second is a payment for the avoided cost of landfill, made to plant operators by the waste-disposal authorities legally responsible for handling waste. It is also proposed to introduce a tax on landfill waste.

Because of such incentives, schemes have been developed that use a variety of waste fuels, including conventional municipal waste, old tires, agricultural residues, methane from landfills, and farm slurry. For every scheme constructed, there is probably more than one other that has been abandoned in the planning process because of intense local concerns about gaseous emissions and the general negative image of waste incineration.[7] This is a growing phenomenon even in countries such as Japan, where waste incineration has been a conventional waste-management strategy. It poses a potential major constraint on achieving certain industrial ecology-based goals.

REJECT HEAT INTO PRODUCTS

Although it may be desirable from an industrial ecology perspective to minimize reject-heat streams by converting as much of the original energy as possible into electricity, a back-up strategy is to convert the heat into a useful application.

Combined Heat and Power and Combined Heat and Power with District Heating

In combined heat and power (CHP), as much as 90 percent (gross) of the fuel energy input can be recovered in a useful form as electricity and heat. Case studies have demonstrated that costs are also reduced with CHP, and payback periods have frequently been shown to be about 5 years. In situations where the heat and electricity requirements can be matched carefully to a plant's ability to switch between maximizing electricity and maximizing heat output, CHP can be particularly effective.

The recent past has seen a considerable increase in the capacity of CHP and CHP with district heating (CHP/DH) installed in the United Kingdom, mainly stimulated by the opportunities for sale of electricity to external consumers after the privatization of the electricity supply industry. Electrical output from such facilities rose 29 percent from 1991 through 1993 (Department of Trade and Industry, 1994). There are now nearly 1,000 installations, about one-third at industrial sites and the remainder at commercial, administrative, and residential locations. Over one-half of the installations are small—under 100 kilowatts—but the large facilities (over 10 megawatts) are responsible for over 80 percent of the CHP and CHP/DH generating and heat-raising capacity.

In 1993, 5 percent of the United Kingdom's electricity was generated at CHP and CHP/DH sites; in the industrial sector, this figure is 14 percent. The industrial sector accounts for 90 percent of the total CHP and CHP/DH generating capacity, with particularly significant use in the refineries and chemical industry sectors. The older CHP and CHP/DH schemes tend to be fired by coal or fuel oil but, as in conventional electricity generation, new schemes are increasingly favoring natural-gas fuel.

There is a growing interest in CHP, particularly CHP/DH, in distributed-energy production systems, leading to discussion of whether there might be a reversal of the concentration of generating capacity into fewer, higher wattage facilities over the past 100 years. In the United Kingdom, this has in part been stimulated by the greater freedom of customer choice in the electricity and gas markets resulting from the privatization of the industries. The implications of such trends, where generation of electricity and supply of heat are conducted at the scale of the individual apartment block (or even, under the most bullish scenarios, within the individual home, with automatic sell-back of surplus electricity and so on), have not yet been thought through.

More conventional CHP and CHP/DH schemes are, however, likely to show a steady growth in application (Brown, 1994). At least 10 projects with a capacity of more than 5 megawatts are under construction in the United Kingdom. The U.K. government has also made increasing the proportion of generating capacity that is CHP or CHP/DH part of its strategy for achieving year-2000 targets for reductions in carbon dioxide emissions. This indicates a conviction in official circles that the expansion of the industry will continue, thereby enabling the government to achieve its goals. The most bullish forecasts from within the electricity supply industry predict up to 25 percent of U.K. electricity derived from cogeneration by 2020 (Harvey, 1994).

Horticulture and Pisciculture

Even with conventional generating plants, there has been some experience in the United Kingdom with schemes to use reject heat for greenhouse production of vegetables or for fish farming. The size of the reject heat stream, given the low conversion factors of the stations involved, is such that the entire national demand for greenhouse heating would be met by the output of just one of the United Kingdom's 2,000 megawatt power stations (Coleman, 1993). If the overall amount of reject heat from electricity generation declines as a result of applying industrial ecology, a better match between availability and demand may reusult.

There will probably continue to be local opportunities for such conversion of reject heat into consumables, but it is likely to remain a minor feature of industrial ecological integration.

Barriers

A major barrier to the more widespread application of the proven technologies of small-scale, gas-fired CHP is the capital cost. Overcoming this barrier has led to the development of new relationships between equipment suppliers and energy uses. There are many variants, but often the supplier of the hardware also provides the financing, whereas the user pays over a period of time from the energy cost savings achieved. Such new energy-service companies are engineering organizations rather than finance houses. They may design, supply, erect, and operate the plant. They may purchase the fuel or the user may do so. Either may sell any surplus electricity. The contractual arrangements between the energy service company and the energy user can be as sophisticated as the parties choose. To encourage energy savings, there can be provisions to share future gains.

CONSTRAINTS

At several points in this paper, barriers have been identified—some of them formidable—that prevent better performance. Innovation is rarely easy, and the widespread introduction of industrial-ecology-based innovations into industrial and commercial life is, by any standards, a major innovative process. It is useful to review the key constraints affecting energy use and production and to explore how these barriers can be overcome.

Energy Prices

Low energy prices do not encourage productive energy use; subsidies need to be removed. In manufacturing, energy is usually a small proportion of total costs. Energy costs, therefore, receive relatively little attention from the financial managers of companies. A perception that energy prices will rise would be a valuable nudge to businesses to give energy productivity more attention.

Lack of Information

There is a pressing need for more information and the dissemination of that information on what is, or will shortly be, possible. Conferences and other discussions help, but industry and commerce are not solely composed of large firms. Small and medium-sized firms are not usually well represented at such meetings. There is a well-recognized need to target such firms with information on concepts and practices. One recognized route is through the influence of large enterprises on their supply chain. This observation does not imply that all small enterprises are unaware of the potentials of improving their energy efficiency or environmental performance. Indeed, it is often they who recognize market niches that go unnoticed by larger enterprises.

A feature of energy production and use is that the interactions and ramifications are so complex that it is not easy to arrive at or convey a straightforward message. There are also conflicting claims by protagonists, which may cause those in a position to act to be confused or dismissive.

Significance of First Cost

For many individual decision makers (especially homeowners), consideration of first cost dominates. There is often a lack of understanding of levelized cost-appraisal methods. To be interested in energy saving, the end user needs to be confident that the savings will materialize. To provide this confidence, there must be well-documented demonstration projects and substantiated indicators of performance. For commercial and industrial investors, there is always concern about the risk incurred by an early investor in an innovative system. Demonstration projects help to allay such concerns (Energy Efficiency Office, 1993).

The Legacy of Adam Smith

A Smithian perspective sees division of labor and functional specialization by enterprises as contributors to a nation's prosperity. Within a firm, the drive for competitiveness leads to pursuit of technical efficiency within the framework of costs and prices as seen by that firm.

Industrial ecology introduces a broader concept—the efficiency of an aggregate of firms within a system—which could be seen as a concept of social efficiency and a new political economy. It will involve bringing together, for mutual benefit, the objectives of individual companies and may result in partnerships between private companies or among government, public enterprises, and private enterprises.

Industrial-ecology-based systems may emerge as opportunities arise for changing the nature and purpose of a company. For example, equipment-supply companies or utilities themselves may decide to turn themselves into energy-service companies.

The Legacy of the Concept of Free Goods

A significant barrier to change has been the tendency to disregard the costs of environmental degradation. There has been a rapid development of the concept of putting a price on the environment and bringing the power of the market to bear on decision making in a way that will increase the attention given to environmental quality considerations. There have been some concrete, practical steps in this direction, particularly in the United States and especially in California. The overall objective is to take account of costs and benefits to obtain environmentally honest prices (Speth, 1992).

VISION

Vision is a key element in major innovation. Vision jumps ahead of extrapolation, freed from perceived constraints, including constraints of the mind. As Jonathan Swift noted, "Vision is the art of seeing things invisible."

Because of the pervasiveness of energy, any vision needs to be consistent with industrial ecology concepts, including connectedness, waste minimization, and limited use of nonrenewable materials. For energy use in the developed areas of any country (regardless of whether the country is considered developed or developing), the vision should

- focus around the needs of customers, often as an aggregation of services that customers require rather than a product, and link society and technology;
- recognize both the contribution that energy makes to society and the need for increased energy productivity;
- recognize the diversity of means of providing energy, including the purposeful direct use of the energy of the sun and other renewable sources, with increased emphasis on distributed production to meet local needs;
- recognize the necessity of bringing the power of the market to bear through environmentally honest pricing;
- include concepts of spatial planning for industry, commerce, and homes;
- consider integrated energy use and the cascading of energy from high-grade to low-grade uses; and
- include new partnerships between private and public enterprises to achieve all these aims.

The task is to develop this vision as an aid to applying industrial ecology in the real world, a world in which energy is political and democratic governments exercise the art of the possible, in which an enterprise working within a complex economic framework needs to satisfy the aims and ambitions of its shareholders, customers, employees, suppliers, and neighbors.

APPENDIX

The Organization of Electricity Supply in the United Kingdom

In England and Wales, there are two major private-enterprise electricity generators and a separate state nuclear-based electricity generating company. The strategic transmission system is a separate private company, currently a wholly owned subsidiary of 12 regional private electricity companies (shortly to be divested). The system takes electricity from the generators, sells it to final consumers, and operates its own distribution network. Some of the regional companies self-generate a proportion of their electricity. There are also some smaller independent generators, and these are playing an increasingly important role. For example, companies with large cogeneration plants may sell surplus electricity to the regional companies or to large private customers, using the regional companies' distribution systems. The generators may also sell directly to large consumers of electricity, using the transmission and distribution systems under the regional companies' control.

In Scotland and Northern Ireland, the electricity utilities (two in Scotland, one in Northern Ireland) handle generation, transmission, and distribution, except that in Scotland there is also a separate state-owned nuclear generating company that sells power to the other two utilities. Electricity can also be exchanged between Scotland and England and between England and France (Figure 2). An undersea transmission link will shortly be constructed between Scotland and Northern Ireland. As a consequence of the recent political developments, plans have been announced to reestablish and further develop an electricity transmission system between Northern Ireland and the Irish Republic.

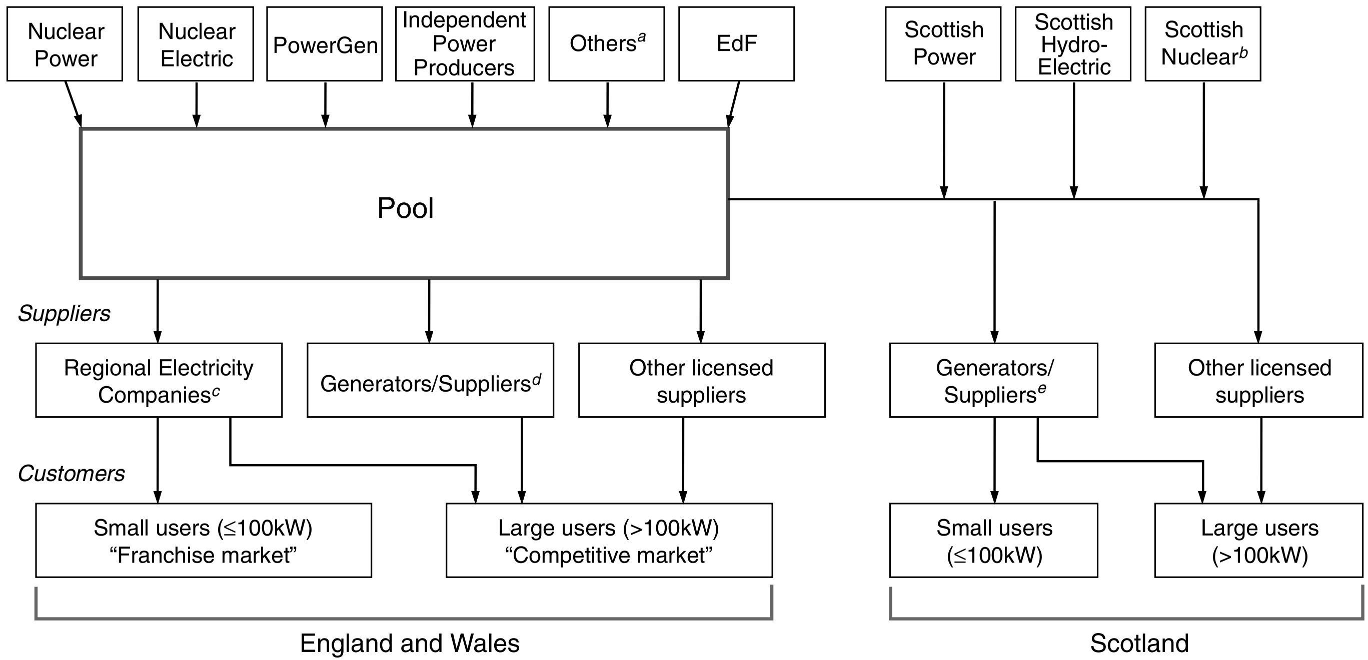


FIGURE 2 Structure of the electricity industry in the United Kingdom. Electricite de France (EDF) is present because electricity can be exhanged between England and France. [a]Including some autogenerators. [b]Other small generators also supply electricity to ScottishPower and Scotish Hydro-Electric. [c]Comprising East Midlands Electricity, NORWEB, Eastern Electricity, SEEBOARD, London Electricity, SWALEC, MANWEB, SWEB, MEB, Southern Electricity, Northern Electricity, Yorkshire Electricity. [d]Comprising National Power, Nuclear Electric, PowerGen, Scottish Power, Scottish Hydro-Electric. [e]Comprising ScottishPower, Scottish Hydro-Electric. SOURCE: Department of Trade and Industry, 1994.

NOTES

1. There has been some discussion in the United Kingdom about the rational use of energy. This paper makes the assumption that a major contribution to achieving this goal is to ensure that all energy costs are tallied, including those related to the environment.
2. This last, of course, would have a special relationship with electricity, because electrolysis is usually identified as the main means of manufacturing the necessary hydrogen supplies.
3. The reasons for this divergence in practice are complex and include the widespread occurrence of municipal provision of electricity generation in continental Europe, which, coupled with a housing function, has encouraged the pursuit of combined heat and power and district heating in several European countries.
4. In this respect, the experience of some of the industrialized countries of East Asia, where population densities and urban-land scarcity often mandate proximity of industrial and residential functions, may be more relevant as these countries strive for environmental quality.
5. In the United Kingdom, such institutional housing providers are local government authorities and, increasingly in recent years, housing associations—nonprofit organizations set up to provide social housing.
6. Solid waste generated from gas-fired plants, furnace cleaning, etc. are orders of magnitude less significant than that from coal- or even oil-fired plants.
7. There have been examples in the United Kingdom of residents' resistance to the proximity of gas-fired and straw-fired power plants.

REFERENCES

Ausubel, J. H. 1992. Industrial ecology: Reflections on a colloquium. Proceedings of the National Academy of Sciences of the USA 89:879–884.

Brown, M. 1994. Combined heat and power—positive progress in the United Kingdom. Energy Policy February:173–177.

Bunn, R. 1993. Changing gear. Building Services May: 27–30.

Coleman, D. 1993. National Power News. August.

Department of Trade and Industry. 1994. Digest of UK Energy Statistics, 1994. Appendix C. London: Her Majesty's Stationary Office.

Energy Efficiency Office. 1993. Good practice case study 62. Best Practice Program, February.

Harvey, K. 1994. The development of combined heat and power in the United Kingdom, Energy Policy February:179–181.

Littler, J. G. F., and R. Thomas. 1984. Design with Energy: The conservation and Use of Energy in Buildings. Cambridge:Cambridge University Press.

Smart, B. 1992. Industry as a metabolic activity. Proceedings of the National Academy of Sciences of the USA, 89:804–806.

Speth, J. G. 1992. The transition to a sustainable society. Proceedings of the National Academy of Sciences of the USA, 89:870–872.

Tibbs, H. B. C. 1992. Industrial ecology—an agenda for environmental management. Pollution Prevention Review Spring:167–180.

The Industrial Green Game. 1997. Pp. 91–100.
Washington, DC: National Academy Press.

The Functional Economy: Cultural and Organizational Change

WALTER R. STAHEL

A functional economy, as defined in this paper, is one that optimizes the use (or function) of goods and services and thus the management of existing wealth (goods, knowledge, and nature). The economic objective of the functional economy is to create the highest possible use value for the longest possible time while consuming as few material resources and energy as possible. This functional economy is therefore considerably more sustainable, or dematerialized, than the present economy, which is focused on production as its principal means to create wealth and material flow.

One aim of this paper is to sketch out a functional economy. The other is to show the social, cultural, and organizational change that may arise in shifting from a production-oriented economy toward a functional or service-oriented economy.

SUSTAINABILITY

Sustainability depends on several interrelated systems. Each is essential for the survival of humans on Earth. This means that priorities cannot be argued over nor can there be speculation about which of these systems humankind can afford to lose first. In fact, humans cannot risk losing ground in any of these areas:

- The ecosupport system for life on the planet (e.g., biodiversity), a factor of the regional carrying capacity of nature with regard to human populations and human life styles;
- The toxicology system (qualitative, sometimes accumulative), a direct

danger to man and the result increasingly of humankind's own economic activities;

- The flows-of-matter system (quantitative), a factor of planetary change (toward a reacidification) and thus a danger to human life on Earth; and
- The system of societal and economic structures, factors contributing to quality of life.

The last item carries the idea of sustainable economy (Coomer, 1981). It encompases the broader objective that includes, besides the natural resource problem, the question of the longevity and sustainability of our societal and economic structures.

This insight was at the basis of the movement that coined the English term "sustainability" in the early 1970s. The emergence of the "green" movement and its use of the term sustainability missed the wider perspective of a sustainable society. The broader perspective includes considerations such as full and meaningful employment and quality of life. That perspective is necessary for understanding the importance of the social, cultural, and organizational changes needed for a more sustainable economy.

THE CONSEQUENCES OF TRADITIONAL LINEAR THOUGHT

Current human systems are the result of linear thinking. For example, the terms "added value," relating exclusively to production, and "waste" at the end of the first (and often only) use phase of goods, are notions of a linear industrial economy. Liability for waste stops at the point of sale, after production and resources are incorporated in goods. In contrast, cycles, circles, and loops have no beginning or end. In a true economy of loops there is no waste in the linear sense, and the economy is similar to natural systems, such as the water cycle.

Present national accounting systems and the use of the gross national product (GNP) measure of success is again an inheritance of the linear industrial economy. Adding income and expenses together is an indication of activity, not of wealth and well-being. Waste management, car accidents, pollution control, and remediation costs all constitute positive contributions to the GNP, at the same level as the manufacturing of goods. This shows a basic deficiency of national accounts. In this old frame of reference, waste prevention corresponds to a loss of income (i.e., it is economically undesirable). From a sustainability view, waste prevention is a reduction of costs that contributes to substantial national saving. For example, the waste management industry in Germany costs the economy (i.e., contributes to GNP) about US $45 billion per year. Waste prevention that reduces the need for this management would therefore contribute to national savings.

When discussing the benefits of moving toward a more sustainable society and metrics to gauge such change, it is important to keep the context of nonsustainable national accounting systems in mind.

RESOURCE-USE POLICIES ARE INDUSTRIAL POLICIES

The choice of the best waste-management strategy is often a self-fulfilling prophecy. The promotion of recycling strategies—closing the material loops—conserves the existing economic structures and is thus easy to implement. Unfortunately, the economic value of recycling declines as the recycling volume increases. An increase in the amount of secondary resources causes an oversupply of materials and depresses the prices of virgin and recycled resources alike. The result is a need to export waste materials and with that comes the problem of oversupply. Future technical innovation in recycling will include improvements in design for the recyclability of goods and new recycling technologies, both of which cannot overcome the basic price squeeze mentioned (Jackson, 1993). Increased recycling does not reduce the flow of material and energy through the economy but reduces resource depletion and waste volumes.

In contrast to recycling, strategies for higher resource efficiency reduce the volume and speed of resource flow through the economy. One of the keys to resource efficiency is the take-back strategy: closing the product and material responsibility loops. However, strategies of higher resource efficiency often counter the validity of the present calculus of economic optimization that ends at the point of sale. At first sight, closed responsibility loops even seem to violate traditional task definition in the economy: Industry produces efficiently, consumers use quickly, and the state disposes efficiently. Strategies to close the product responsibility loops, such as the voluntary or mandatory take-back of consumer goods, impose structural changes and are thus more difficult to implement than the recycling of materials. Because these strategies are based on innovative corporate approaches, such as Xerox's asset management program, they are highly competitive as well as sustainable. These strategies will become even more competitive as the functional economy develops and energy prices rise (Stahel, 1994). Future technical innovations that can be expected in this field are those that enable the use of remanufactured and upgraded components and goods, and commercial innovations to keep goods in use as long as possible.

Strategies to achieve a higher resource efficiency through an optimization of the use of goods are measured as resource input per unit of use over long periods of time and will cause substantial structural change within the economy.[1] The change will not be easy but these strategies will also have the biggest positive impact on industrial competitiveness. Early adoption may thus give a considerable long-term advantage to companies that dare to change first. Among the strategies for a higher resource efficiency are those for a longer and more intensive use of goods, those for dematerialized goods, and those for innovative system solutions (Table 1). Among the innovations to emerge from a promotion of higher resource efficiency are new technical and commercial strategies to improve use. There have also been innovations in redesigning components, goods,

TABLE 1 Resource Efficiency and Business Strategies in the Service Economy

	Implementation of Strategies	
	Closing Material Loops (technical strategies)	Closing Liability Loops (commercial/marketing strategies)
Resource Efficiency Strategies		
Reduce the volume of the resource flow	Ecoproducts • *dematerialized goods* • *multifunctional goods*	Ecomarketing • *shared utilization of goods* • *selling utilization instead*
Reduce the speed of the resource flow	Remanufacturing • *long-life goods* • *product-life goods* • *cascading, cannibalizing*	Remarketing • *de-curement services* • *away-grading of goods and components* • *new products from waste*
Reduce the volume and speed of the resource flow	System solutions • *Krauss-Maffei plane transport system*	Systemic solutions • *lighthouses* • *selling results instead of goods* • *selling services instead of goods*

and systems that reduce material use in manufacturing and in reducing the costs of operating and maintaining the goods in use.

THE PROBLEM OF OVERSUPPLY

The economies of industrialized countries are characterized by several key factors (Giarini and Stahel, 1989/1993):

- Their populations account for only 20 percent of the world population but for 80 percent of world resource consumption.
- Their markets for goods are saturated and the stocks of goods represent a huge storage of resources. For built infrastructures, there is also an increasing financial burden with regard to operation and maintenance costs.
- Their economies suffer from oversupply, which indicates that the old remedy of a higher economy of scale (centralization of production to reduce manufacturing costs) can no longer solve the economic problems or the sustainability issue. The reason for this is that the cost of the services that are instrumental for production are a multiple of the pure manufacturing costs; a further optimization of production therefore does not make economic sense.
- Incremental technical progress is faster than product development; substituting new products for existing ones will increasingly restrain technological progress compared with the alternative of a faster technological upgrading of existing goods.

The trend toward a higher resource efficiency and a dematerialization of goods and systems will further increase the economic woes of the base-material production and recycling sectors, because demand and prices of many materials will continue to fall.

The situation in many developing countries, however, is radically different. These countries will continue to experience a strong demand for basic materials for the construction of their infrastructures and will continuously suffer from a shortage of affordable resources and goods, including food, shelter, and infrastructure and services for health and education. Transfering the surplus goods and materials of good quality and appropriate technology from industrialized to developing countries may be a solution to both problems.

THE GENESIS OF A SUSTAINABLE CYCLE

Several changes in how we think about economics are necessary for understanding a "life after waste" industrialized society. A critical change is to shift to a service (cycle) economy (Table 1) (Giarini and Stahel, 1989/1993). Cycles have no beginning and no end. Economically, the most interesting part of the cycle and new focal point is the stock of existing goods in the market. Economic well-being is then no longer measured by exchange value and GNP, but by the use value of a product and the wealth presented by the stock of existing goods.

Long-term ownership of goods becomes the key to the long-term (rental) income of successful companies, and with that ownership comes unlimited product responsibility. Strategies of selling the use of goods instead of the goods themselves (e.g., Xerox selling customer satisfaction) and providing incentives to customers to return goods to manufacturers become keys to long-term corporate success. The adaptability of existing and future goods to changes in users' needs (for rentable products) and to technological progress (to keep them current with technological progress) becomes the new challenge for designers and engineers. The economic structure must maximize the return from these new resources (many existing goods in a dispersed market). An adaptation of today's economic, legal, and tax structures to these new requirements may be a precondition for countries to attract and breed successful economic players for a sustainable functional society.

Several multinational companies such as Schindler and Xerox have already started to successfully implement these new strategies. Schindler sells "carefree vertical transport" instead of elevators, a strategy that provides all the services needed by customers (i.e., maintenance, remanufacturing, and technological updating of the hardware). In addition, there is a telephone connection linking every elevator 24 hours a day to a centralized emergency service center. In collaboration with the decentralized maintenance crews of the seller, this system ensures that no person ever gets stuck for more than a few minutes in a elevator that has stopped functioning.

Xerox's asset management program is focused on selling photocopying services instead of photocopiers. Asset recycling is now part of a new business process that includes an asset-recycling management organization. Xerox is decoupling manufacturing volume from turnover and profits, regionalizing activities, and changing skill pools and employee responsibilities accordingly.

A reduction in the flows of matter through the economy can be achieved by decreasing the volume of flow (through innovative multifunctional products and a more intensive use of products and system solutions) or by slowing the speed of flow (e.g., through the remanufacturing and remarketing of goods to extend product use) (Figure 1).

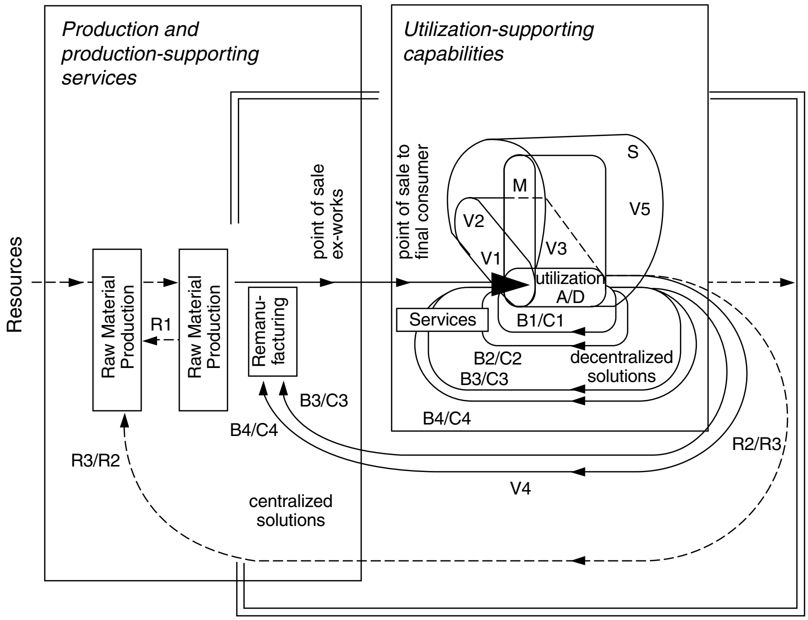
Slowing the speed of flow is a feasible proposition for all countries. However, developing countries will need to increase the volume of their resource flow for economic development and to build basic infrastructure. Industrialized countries can achieve sustainability by slowing down resource flows.

STRATEGIC AND ORGANIZATIONAL CHANGES

In contrast to the manufacturing economy, economic success in the sustainable service economy does not arise from mass production but from good husbandry and stewardship. Economic rewards come from minimizing tasks needed to transfer a product from one user to the next. Local reuse after a quality check or repair by the manager's representative is the smallest possible cycle in Figure 1 and the most profitable strategy. A product that can no longer be commercialized (i.e., rented or used) will be remanufactured and upgraded, or, in the worst case, be dismantled with the aim of reusing its components for new products.

To achieve the smallest cycles, a different economic and organizational mindset is necessary in several areas:

- The industrial structure for manufacturing and remanufacturing activities will have to be unified and regionalized. Location of these activities will have to be closer to the market assets, and this proximity means handling smaller (re-) manufacturing volumes. Appropriate methods for such purposes will have to be developed and higher-skilled labor will be required. The cost for such a change is offset by dramatic reductions in purchases of materials and the virtual elimination of disposal costs.
- Products will have to be designed as technical systems that are part of predesigned modular master plans. Such plans will facilitate ease of maintenance and ease of out-of-sequence disassembly by workers or robots.
- Components will have to be designed for remanufacturing and technological upgrading according to the commonality principle. This principle was first used by Brown Boveri Company in the 1920s to design its revolutionary turbocompressors. It has been perfected by Xerox in the 1990s in the design of its copiers. The commonality principle promotes standardized multiproduct function-specific components that are interchange-



CLOSING THE MATERIAL LOOPS

I. Strategies for slowing down the flow of matter through the economy
   A. Long-life goods: Philips induction lamp, Ecosys printer
   B. Product-life extension of goods:
      B1. Reuse: reusuable glass bottles
      B2. Repair: car windscreen, flat tire
      B3. Rebuild: retreaded tires, renovated buildings
      B4. Technology upgrading: Xerox copier 5088, PC-AT,
   C. Product-life extension of components:
      C1. Reuse: refill printer cartridges, roof tiles
      C2. Repair: welding of broken machine parts
      C3. Rebuild: revacuum insulating windows
      C4. Technology upgrading: upgrading of jet engines to new noise standards
   D. Remarketing new products from waste (product-life extension into new fields)
II. Strategies for reducing the volume of matter through the economy
   M. Multifunctional goods: Siemens 'FAX', Swiss Army knife, adaptable spanner
   S. System solutions: micro cogeneration of cold or heat and power, road rail

CLOSING THE LIABILITY LOOPS

I. Strategies for a cradle-to-cradle product responsibility
   V. Commercial or marketing strategies
      V1. Selling use instead of goods: operational leasing of cars, aircraft, trucks, construction equipment, medical equipment, photocopiers, apartment rentals
      V2. Selling shared-use services: laundromat, hotels (beds),
      V3. Selling services instead of products: lubrication quality instead of engine oil
      V4. Selling results instead of products: pest- and weedfree fields instead of agro chemicals, individual transport instead of cars
      V5. Monetary bring-back rewards: 10-year cash-back guarantee

FIGURE 1 Strategies for higher resource efficiency. SOURCE: Adapted from Stahel, 1992, 1993, and 1994.

able among different product lines. These standardized components are often maintenance free, self-protecting, and fault tolerant, which greatly reduces operating costs (such as operator and repairman training, and spare-parts management for complex products).

- New technologies aimed at optimizing the resource efficiency and safety of products and components over long periods of time will have to be developed. These include spareless repair methods, in situ function-quality monitoring systems, and memory chips for life cycle data.
- New professions and job qualifications will emerge, such as operation and maintenance engineers. The salespersons of the past will have to become customer advisors able to optimize generic products for the needs of specific users, and to upgrade products according to the wishes of the user as technology advances.
- Users (exconsumers) will have to learn to take care of the rented or leased products as if they owned them, to enjoy the new flexibility in product use offered by a use-focused service economy. Whereas in the industrial economy, misuse and abuse of products lead to a punishment in the form of increased maintenance cost for the owner-user, in the service economy they may lead to the exclusion of a user from the use-focused system.

OBSTACLES, OPPORTUNITIES, AND TRENDS

Many obstacles will need to be overcome on the way to an economy optimizing use-cycles. Most of these obstacles are embodied in the logic of the present linear industrial economy. A supply definition of quality, for example, is based on warranties limited to 6 or 12 months for manufacturing defects only and on the newness of components in new goods. The logic framework of a functional economy requires a demand-side definition of quality based on unlimited customer satisfaction and the guarantee of a system functioning over longer periods of time.

The signs on the horizon clearly point to a use-focused economy:

- The European Community-directives on product liability and more recently on product safety and the draft directive on service liability all stipulate a 10-year liability period.
- Some car manufacturers offer a total cost guarantee over 3 or 5 years, which includes all costs except tire wear and fuel.
- Industry shows an increasing willingness to accept unlimited product responsibility and to use it aggressively in advertising, through money-back guarantees, exchange offers, and other forms of voluntary product take-back and is learning to make product retake and remarketing a viable business division.

- Out-sourcing is rapidly becoming a generally accepted form of selling results instead of (capital) goods or services.

Companies and regions that initiate the change toward a sustainable society rather than suffering the consequences of it through the actions of their competitors will have a head start and be able to position themselves strategically. An old, but in the age of market research somewhat forgotten, truth of economics will play its heavy hand again: Real innovation is always supply driven—the role of demand is one of selection (Giarini and Stahel, 1989/1993).

SUMMARY AND CONCLUSIONS

The shift in the economy toward a more sustainable society and functional economy began some time ago. However, most experts are unaware of the fundamental change, probably because they interpret the signs in terms of the old industrial economic thinking.

A functional society will not solve all the problems of this world, especially not the inherited problems from the past (e.g., pollution cleanup and unemployment of overspecialized production workers); nor will it make the manufacturing sector disappear. The manufacturing sector could well be transformed into a high-volume producer of global standardized components engaged in regionalized remanufacturing of products.

A sustainable economy needs an appropriate structure. The characteristics include a regionalization of jobs and skills, such as minimills for material recycling, remanufacturing workshops for products, decentralized production of services (e.g., rental outlets), local upgrading and take-back (comparable with insurance supplemented by centralized design, research, and management centers). Such an economy will consume fewer resources and have a higher resource efficiency, and its production will be characterized by smaller regionalized units with a higher and more skilled labor input. Transport volumes of material goods will diminish and be increasingly replaced by transports of immaterial goods such as recipes instead of food products, software instead of spare parts.

For the first time since the beginning of the Industrial Revolution, the economy will offer workplace mobility rather than rely on worker mobility. The more that immaterial goods are transported, the greater the feasibility of telecommuting. Flexible work periods and part-time work are compatible with, and even a necessity for, providing services and results around the clock.

Because services cannot be produced in advance and stored but have to be delivered at the location of the client when needed, the economic disadvantages of peripheral suburban zones will partly disappear, as will most of the environmental burden caused by transportation flows to centralized zones.

Waste management could increasingly become a subject for historians rather than economists as large companies reach their goals of zero waste by 2000.

NOTE

1. The measure of resource input per unit of use became popular in Europe as material inputs per service unit (MIPS) after the publication of a book by Professor Friedrich Schmidt-Bleek (1994).

REFERENCES

Coomer, J. C., ed. 1981. Quest for a Sustainable Society. Elmsford, N.Y.: Pergamon Policy Studies.

Giarini, O. and W. R. Stahel. 1989/1993. The Limits to Certainty—Facing Risks in the New Service Economy. Boston, Mass.: Kluwer Academic.

Jackson, T., ed. 1993. Clean Production Strategies, Developing Preventive Environmental Management in the Industrial Economy. Boca Raton, Fla.: Lewis.

Schmidt-Bleek, F. 1994. Wie viel Umwelt braucht der Mensch? MIPS - Das Mass fur Ökologisches Wirtschaften. Berlin: Birkhäuser Verlags AG.

Stahel, W. R. 1992. Product design and waste minimization. Pp. 91–98 in Waste Minimization and Clean Technology: Waste Management Strategies for the Future, W. A. Forester, and J. H. Skinner, eds. New York: Academic Press Harcourt Brace Jovanovich.

Stahel, W. R. 1993. Life expectancy of goods and future waste. Pp. 29–35 in International Directory of Solid Waste Management 1993/4—The International Solid Waste Association Yearbook. Kobenhavn, Denmark: International Solid Waste Association.

Stahel, W. R. 1994. The utilization-focused service economy: Resource efficiency and product-life extension. Pp. 178–190 in The Greening of Industrial Ecosystems, B. R. Allenby, and D. J. Richards, eds. Washington, D.C.: National Academy Press.

The Industrial Green Game. 1997. Pp. 101–113.
Washington, DC: National Academy Press.

Environmental Constraints and the Evolution of the Private Firm

BRADEN R. ALLENBY

Several trends and proposals reflecting rising global environmental concern implicitly suggest that private, for-profit firms[1] in an environmentally constrained world are evolving away from profit-seeking behavior towards more socially comprehensive goals.[2] It is not apparent, however, that the implications of such an evolution have been defined and considered. It is also arguable that progress toward environmental sustainability can best be achieved by modifying the boundary conditions within which private corporations operate rather than by trying to change them into organizations that reflect social goals beyond profit seeking. If this hypothesis is true, it suggests that the social and legal responsibilities of corporations should not be inadvertently and unthinkingly expanded beyond those currently established but, rather, that wise policy should create incentives for corporations to behave in ways supporting the achievement of sustainable societies.

Corporations are pivotal economic agents in any modern economy. They reflect and create the cultures and economies within which they function.[3] Created and defined by law, corporations may also be modified by law. Several questions arise: What forms of corporate structure are currently evolving? Are these new forms of corporate structure most likely to contribute to the evolution of economic structure and behavior that is dynamically stable over the long term in an environmentally constrained world?

It is doubtful that we know enough yet to answer these questions definitively, but we can identify the trends that might drive redefinition of the corporation, lay the groundwork for a rational discussion of the desirability of any such redefinition, and propose a tentative position.

THE PRIVATE FIRM

The private corporate enterprise is such an intrinsic part of the modern capitalist economy that few realize its relative youth. The antecedents of the corporation can be traced back to the medieval merchant guild systems or, more recently, to trading companies enjoying monopolies granted under royal charter, such as the British East India Company. However, the advent of the truly modern firm is tied to the development of general incorporation laws, under which any entity meeting statutorily defined criteria was able to incorporate, rather than requiring the special grants of privilege that had hitherto prevailed. In the United States, the first of these laws was passed in 1811 by New York State (Vagts, 1973). The pattern subsequently established in Western economies--a complex network of independent firms, frequently competing on the basis of technological and scientific creativity, with successful innovation rewarded in the marketplace--became the basis for modern, materially successful economies (Rosenberg and Birdzell, 1990). Thus, the modern corporation appeared at a certain stage in the increasing complexity of economies arising from the Industrial Revolution, and, arguably, was then responsible for their continued evolution.

The fundamental purpose of a for-profit corporation in a free market economy is to make money for its owners, that is, the shareholders. This point is made vigorously by Milton Friedman (1962): "Few trends could so thoroughly undermine the very foundations of our free society as the acceptance by corporate officials of a social responsibility other than to make as much money for their stockholders as possible. This is a fundamentally subversive doctrine." It is, of course, now generally recognized that firms to a greater or lesser extent reflect the interests of many stakeholders, including their employees, their managers, their customers and, increasingly, different governments in a global economy. Corporate charitable contributions, for example, are generally legal if they are reasonable, and the firm's directors have broad discretion to take such actions if they help protect the corporation's interests. Firms from cultures less individualistic and adversarial than that of the United States, such as those in Europe or, especially, in Japan, tend to display a somewhat greater propensity to internalize select public interest.

Inability to optimize one goal (or wisdom in a complex and rapidly changing environment) may lead firms to try to *satisfice* (meet minimum levels of performance) several goals, rather than focus on one (Scherer, 1980). Additionally, firms, like any agent, evolve in structure to reflect changing boundary conditions, such as, for example, shifting from a authoritarian management model and hierarchical structure appropriate to mass-production manufacturing to a flatter, specialist-based, information-rich organization reflecting changes in technology and global market conditions (Dertouzos et al., 1989; Drucker, 1988). Nonetheless, it remains true that, broadly speaking, seeking profits remains the primary goal of the private corporation and that the public-interest theory, which was especially popular in the late 1960s, has not been generally accepted.

Do recent developments in environmental policy, or even our growing understanding of the interactions between economic activity and fundamental natural systems, indicate that the current concept of the firm is inadequate in an environmentally constrained world? Corporations coevolved with the Industrial Revolution; they are its creatures as well as its creators. If the Industrial Revolution must be reengineered to be sustainable (Graedel and Allenby, 1995), is the same true of private corporations?

REDEFINING THE FIRM

There has been little explicit recognition that inherent in the integration of technology and environment—a likely prerequisite to any meaningful increase in the sustainability of global economic activity—are implicit drivers for redefining the corporation. Major drivers include the following:

- *The arguably fundamental conflict between uncontrolled growth as a goal of profit-driven private firms and an environmentally constrained world (Costanza, 1991; Daly and Cobb, 1989).*

If a sustainable state requires bounded resource use and material flows, it presents a conflict between the traditional goals of the firm—maximization of value and growth of value over time for shareholders—and the firm's achievements. There are, however, conditions under which individual firms might grow even if unlimited economic growth (as opposed to economic development) is incompatible with sustainability. Some firms, for example, may continue to grow within a sector at the expense of less efficient firms even if the sector itself remains the same size or shrinks. Moreover, as sustainability is approached, some economic sectors will undoubtedly grow at the expense of others as the economy restructures itself. For example, sustainability may require the substitution of information and intellectual resources for material and energy inputs during manufacture or use, leading to an expansion of the electronics and telecommunications sector in the economy as a whole.[4] Some forms of service, such as creating appropriate software applications, may contribute to dematerialization of the economy; firms providing such products could, and should, increase their value as sustainability is approached.

Only when the growth orientation of corporations results in the inappropriate growth of the economy and environmental stress may sustainability be challenged. Corporations could retain a strict growth incentive, but society could create boundary conditions that preclude unsustainable economics. For example, the availability of physical inputs to the economy as a whole could be limited, either through increasing fee or tax structures, or the (more inefficient) use of regulatory bans and limits.

- *The growing recognition that sustainability will likely require the rapid evolution of appropriate technology, and that corporations are the repository of technological competency in a free-market economy.*

Despite the tendency of many environmentalists to distrust technology, achieving sustainability quite likely will require better technology (Allenby, 1993; Elkins, 1993; Graedel and Allenby, 1995). Moreover, the rate of degradation of natural systems (e.g., loss of biodiversity, degradation of agricultural lands, and mining of groundwater) argues that the evolution of environmentally appropriate technology must occur relatively rapidly or social, cultural, and economic systems may not be able to adapt gracefully to an environmentally constrained world. Generally, in free market economies, technology as a broad competency resides in corporations. (There are exceptions, such as the national laboratory system in the United States, but these are relatively rare and tend to focus on specific missions, such as space exploration or military technologies.)

Taken together, the hypothesis of technology as critical to sustainability and the fact that technology generally resides in corporations imply that private firms will be critical to any movement toward sustainability (Allenby, 1994; Organization for Economic Co-Operation and Development, 1992). External and boundary conditions can be changed through incentive- and control-based policies to elicit profit-oriented behavior that evolves technology for sustainability goals. Alternatively, firms can fulfill this function by making sustainability a specified internal goal. The mechanics of accomplishing this are unclear, at best, especially because in many cases sustainability may conflict directly with at least the short-term profit motive. Relying on changes in customer demand patterns for more environmentally appropriate products and services to effect this shift raises the difficult initial question of how to change customer preferences such that they result in firm behavior supporting a sustainable economy.

In practice, of course, a combination of these factors is coming into play. Some customers are demanding environmentally appropriate products, to the extent such products can be defined (which is frequently to a much lesser degree than the public, environmentalists, or industry technologists understand). Some firms are exploring ways to include uncosted externalities (social costs) in their management decisions, at least qualitatively. Governments are establishing regulatory constraints, fee structures, and market information mechanisms (such as ecolabeling or community right-to-know data on release) that, intentionally or not, elicit environmentally preferable corporate behavior. However, these efforts tend to be sporadic, internationally uncoordinated, substance specific, localized in time and space, and without a sophisticated, coordinated effort to help technology (and firms) evolve toward sustainability.

- *The increasing pressure to include environmental costs, not just economic costs, into the management decisions of firms.*

Recent years have seen considerable progress in developing methodologies to determine the environmental impacts of substances and products over their life cycles. Among these are life cycle assessment, or life cycle analysis (both known as LCA) (Keoleian and Menerey, 1993; Netherlands Company for Energy and the Environment, 1992; Society of Environmental Toxicology and Chemistry, 1991), and design for environment (DFE) (Allenby, 1992; American Electronics Association, 1993). Such tools would not be necessary if prices of inputs accurately reflected all externalities. In the absence of such pricing, these methodologies identify social costs not captured in the economic costs on which the firm traditionally relies. The firm is then expected to modify its behavior on the basis of the results of using the tool. Despite obvious problems in quantifying many environmental impacts (e.g., how much is a species worth, or is that even a morally acceptable question?), the development of such tools has been driven by entities--including private firms--that use them for material, process, and technology choices; product design; and management decisions in general.

The internalization of environmental externalities, through LCA and DFE practices, shows that firms are seeking greater social efficiency within existing economic constraints. Thus, for example, if a DFE analysis establishes that one polymeric system is environmentally preferable to another, and the costs are roughly equivalent, no economic penalty has been paid but social costs can be lowered. Except in very rare situations, firms are precluded from choosing inputs, no matter how environmentally preferable, that render their products uncompetitive because of a concomitant cost, quality, or time-to-market penalty.

Such internalization marks a fundamental questioning of the existing rationale of the private firm. The corporation is being asked to make decisions about its operations, products, and services on the basis of something other than economic costs, including externalities that, although they may result from the firm's choices and operations, are not costed in the market. It can be argued that decisions based on such criteria are in the long-term interest of the firm. For example, such practices add value to the firm's trademark as they enhance the perception of the firm as a good corporate citizen. More broadly, it is in the firm's interest to ensure a stable path to a sustainable future so that it may remain in existence and profitable. At least in the short term, however, the firm is being asked to move away from a profit orientation.[5]

Ironically, some business leaders are urging that all environmental command-and-control regulatory mechanisms be dismantled in favor of a responsible industry–government incentive regulatory regime. Regardless of the dubious political viability of this option, it certainly implies a high degree of internalization of social costs by the responsible firm. Whether those urging this approach understand that they are implicitly arguing for a fundamental redefinition of the private firm is unclear.

- *The disconnect between the scope and scale of private firms and their environmental impacts.*

Virtually all modern approaches to environmental issues begin with the assumption that the appropriate scale of analysis is the life cycle of the material, product, or service at issue. A life cycle approach is clearly necessary and desirable if the inefficiencies and suboptimal results of localized optimization at the expense of the overall performance of the system are to be avoided. One example occurred with "air stripping" of volatile organics, which cleaned the water but generated air pollution. Such solutions usually resulted from decisions targeting single medium problems with little if any thought given to resultant systematic impacts.

However, there is an obvious disparity between the scope and scale of even the largest firms and the life cycles of their materials, technologies, products, and processes. Firms manufacturing complex articles do not usually extract or perform initial processing on the materials they use. That is done by petroleum, mining, or chemical companies. Manufacturing firms also do not usually manage the products after the consumer is through with them, nor do they manage the material streams that may result from the dismantling or recycling of postconsumer products. Conversely, firms providing raw materials for the economy seldom have a detailed idea of how their industrial customers are using, formulating, or disposing of excess material. This structure has arisen for economic and historical reasons, with each firm seeking a position in a relatively limited number of markets where its core competencies give it a competitive advantage. The structure is also the result of legal actions. In virtually all market economies, some form of antitrust regulation controls both the scale (size within markets) and scope (vertical combinations) of private firms, although the mechanisms and stringency of regulations vary considerably depending on the country. Moreover, in many cultures, especially that of the United States, large organizations are generally disfavored.

Environmental policies are in the short term moving toward take-back policies for packaging and products. Under these policies, the manufacturer is responsible for taking back its packaging and products after the consumer is through with them and refurbishing, recycling, or properly disposing of them. Especially in Europe, policy discussions are beginning to suggest that manufacturers implement programs to extend product life. Under these programs, products are refurbished and returned to commerce as a step toward the "functionality economy," where firms sell functions, not products, to consumers (Stahel, this volume; Stahel, 1994). In such an economy, for example, an automobile company would lease cars to consumers but remain responsible for the maintenance of the vehicle and all aspects of material management, from choice of inputs, routine maintenance, materials, and lubricants, to recycling the materials once the car was retired from service.

Thus, product-take-back systems and the functionality economy imply a significantly expanded firm in many cases.[6] This expansion could take the form of virtual firms, formed through contractual arrangements to provide direct primary customer interfaces, or of industry consortia, formed to establish standards of performance and design. In some societies, such as Japan with its virtual integration of different firms in keiretsu, the existing economic structure is such that this may not be a problem. In other societies, such as in the United States, it could be a substantial change from the status quo, posing significant legal (e.g., antitrust) and political challenges. The pressure on larger commercial entities, which can be made responsible for their impacts broadly through time and space, is apparent and will undoubtedly increase given the global scope of commerce and the recognition that many environmental concerns are also global.

RESPONSES OF PRIVATE FIRMS

Even within the constraints of existing profit-satisfying behavior, private firms' behavior is already changing significantly as a result of environmental trends and regulations. Firms routinely adjust to external and internal stimuli, especially customers and each other. The question is not whether change will occur; the question is how fundamental that change will be, especially as evolutionary change may well make more fundamental change less problematic.[7]

There are many examples of the evolution of the private firm in response to environmental stimulus. Corporate environmental codes of behavior, both at the firm level and at the trade-group level, have proliferated. Examples include the Principles of the Business Charter for Sustainable Development developed by the International Chamber of Commerce in 1991 and the Responsible Care Program and Product Stewardship Code developed by the Chemical Manufacturers Association (CMA) in the United States. Elements of these codes begin to reflect the trends discussed above. For example, the CMA Product Stewardship Code includes a requirement that CMA members encourage distributors and direct product receivers to implement proper health, safety, and environmental practices, an indirect extension of the CMA member firm into the customer chain resulting directly from the desire to improve the life cycle impacts of the product (in this case, at the use stage). Other trade-group activities include the development of guidebooks for environmentally preferable technologies and practices, such as the American Electronics Association's DFE manual, which is aimed at institutionalizing life cycle approaches and DFE practices in the electronics sector (American Electronics Association, 1993).

Regulatory programs already in effect also reflect these trends. Germany has adopted a packaging take-back law; Netherlands has also done so through an agreement, or covenant, with relevant industrial associations. Postconsumer take-back of complex manufactured products is being considered in Germany, Netherlands, Sweden, Austria, Denmark, France, Japan, and other countries and is already a part of some voluntary ecolabeling schemes (such as the Blue Angel requirements for personal computers).

The U.S. requirement that firms report their emissions of designated substances under so-called community right-to-know requirements has had a strong effect on corporate behavior. Emissions of listed materials have declined substantially, and reduced emissions and pollution prevention are now part of the technology choice process for many facilities. Significant in themselves, such regulatory requirements—and their reflection in most of the industrial codes of behavior referenced above—are a first step toward manufacturing becoming a collaborative effort among the firms involved, the suppliers and customers, the community in which manufacturing occurs, and the host culture (Graedel and Allenby, 1995). Those who were not in manufacturing when each facility was a barony unto itself (as is still true in too many cases) cannot realize what a fundamental cultural change has already taken place within leading firms.

WHAT IS TO BE DONE?

The above discussion indicates that there are at least some powerful trends driving a redefinition of the firm. In particular, these drivers—which face equally strong opposing forces—would tend to create a firm that is larger in scale and scope and that has explicitly assumed at least some of the responsibility for mitigating existing environmental perturbations and transitioning toward a more sustainable global economic state. The implications of such an evolution of the firm are substantial, and a few of these are highlighted below. It is worth noting that the discussion becomes unabashedly speculative at this point.

Shifting to an environmentally sustainable future places inconsistent demands on firms. On the one hand, it is likely that the rapid evolution of environmentally appropriate technologies—with technology taken in its broadest sense as the means by which a society provides its members with quality of life—is necessary to avoid potential discontinuous shifts in natural systems (environmental catastrophes). Rapidly changing markets containing highly competitive firms tend to be the most innovative and would thus be desirable in an economy moving toward sustainability. On the other hand, as discussed above, the economic and social trends generated in response to those perturbations appear to be implying the need for larger firms in more collaborative structures with significant, if unspecified, public interest components in their goal structures. Such an economic structure could well be less competitive, less innovative, and less conducive to rapid technology diffusion than today's structure and thus could hinder rapid technological evolution.

It is also likely that, at least initially, those public interest components will be imposed by regulation rather than internally generated; they are thus liable to be rigid rather than flexible. Technologies will be frozen and incentives for innovation reduced, not expanded. Certainly, that is the case in the United States. Laws such as the Resource Conservation and Recovery Act or the newly amended Clean Air Act are characterized by inflexible regulation of frequently outdated end-of-pipe control technologies rather than policies designed to elicit desirable corporate behavior and technological evolution. Large, inflexibly regulated organizations are not noted for their innovative strength or ability to change rapidly.

Moreover, assume for discussions' sake that it is desirable for firms to become largely responsible for achieving sustainability and thus develop the requisite power to perform the necessary functions, probably at the expense of the nation-state. The transition period would be quite difficult. The credibility of private firms on environmental issues is minimal at best, and public trust is virtually nonexistent. How would firms be regulated over the transition period to assure that they were able to meet accountability standards demanded by political reality (and imposed by a public that is, for all intents and purposes, technologically and environmentally illiterate) while they experiment with sustainability strategies?[8] Surely in such a political environment, the pressure of regulation on corporate activity would be substantial.

In sum, there is a need for accelerated flexibility and innovation at a time when trends seem to favor large, relatively inflexible organizations. This is not an insoluble dilemma, but it calls for far more sophistication than has been yet demonstrated.

Another subtlety is that it is not the development but the diffusion of environmentally appropriate technologies that is critical. New technologies are developed all the time; most, even if environmentally preferable, are discarded for any a number of reasons. Only technologies that actually diffuse through the economy and thus change (hopefully reduce) the environmental impacts associated with providing a unit of function to the consumer are meaningful to the question of sustainability. This makes the question of the proper structure of the firm even more complex. Technology development is an engineering and scientific function, but technology diffusion becomes a question of culture, firm organization (both formal and informal), public policy, and a myriad of other, complex, social phenomena that are not well understood.

Having identified some of the difficulties raised by current trends, let us return to the fundamental question: What form of agents within the existing economic system and what boundary conditions on their behavior will be most effective in moving the economy toward sustainability, given that sustainability is likely to be an emergent characteristic of a suitably self-structured economic system and thus difficult to define a priori? To this question a tentative answer is offered, albeit more in hopes of stimulating discussion than in any firm belief in its correctness.

Initially, an interesting conceptual point should be noted. This paper is implicitly assuming that, through policies or individual initiatives, firms can be structured within the context of a complex economy to migrate toward a long-term stable carrying capacity, or sustainability. Sustainability, however, is quite possibly going to be an emergent characteristic of a properly bounded and structured economy, thus unrecognizable until achieved. One must wonder whether we are capable of understanding this complex system (or acting on that understanding) so as to structure it to result in the emergence of the desirable self-organization. In simple terms, what does it mean operationally when a complex system (ourselves, our cultures, our economies) begins to become so fundamentally internally self-referential? This is not, obviously, a new issue. Throughout history, people have taken great pleasure in writing about themselves in myriad ways. Nonetheless, the issue is now raised in a more critical context. Avoiding serious cultural, social, economic, and population perturbations may depend on humanity's ability to understand complex systems (economies, and physical, financial, cultural as well as underlying natural systems) and how and where we may be able to interfere with and change them constructively. This is not a skill we as individuals or societies have developed.

In this light, then, there may be one significant advantage to the profit-driven model of the corporation: It is relatively easy to establish meaningful boundary conditions for such an agent. Simplistic economic models to the contrary, firms already incorporate many aspects of their cultures and societies within their operations and are able to adopt more even as the dominance of the profit motivation is maintained. Manufacturing as a collaborative effort, increased environmental responsibility within economic constraints, and new models of interfirm organization to implement life cycle programs and responsibilities are trends that imply but do not necessitate a broadening of the firm's mandate to include, for example, responsibility and authority for achieving sustainability. Moreover, maintaining the primacy of the profit motive in a sense maintains the natural selection pressures of the economy, which are arguably critical if rapid evolution within the system is sought. No externally imposed regulatory mandate can substitute for the constant pressure, the brutal frankness, of potential commercial failure. We want to maintain Schumpeter's "gale of creative destruction" precisely because we need creativity and evolution.

If, however, private corporations are to remain narrowly defined, public policy must become far more sophisticated. What will be required is the establishment of boundary conditions that propel the evolution—especially diffusion—of environmentally appropriate technologies leading to the achievement of sustainability, when those technologies cannot be defined until after the fact. Some aspects of such a policy can be defined: more and better data on emissions, environmental impacts, and their sources; possibly properly designed product take-back and producer-responsibility requirements; and price adjustments to internalize externalities. In a broader sense, we need much more information and knowledge to do this. For example, it is arguable, if not apparent, that complex systems such as the economy tend to self-organize and exhibit distributed, not centralized, control, feedback, and internal regulatory systems (Allenby and Cooper, 1994). How can such distributed self-organizational behavior be stimulated, given that price structures, which might perform such a function, are unlikely to include all relevant environmental externalities for the foreseeable future? How can we get there as a practical matter, when most existing environmental regulation, at least in the United States, is predicated on precisely the opposite assumption—the need for specific, mandated, central micromanagement of all behavior bearing on the environment?

The details are daunting, but we may come under more stringent selective pressures than we expect or desire as environmental perturbations become manifest, which may result in far more rapid change than we anticipate. Nonetheless, it seems at least defensible that it is desirable to maintain the current fundamental structure of private corporations while not interfering in the adjustments they are already making (as discussed above) and placing far greater emphasis on understanding industrial ecosystems so as to be able to define and implement appropriate public policy. Such policy, in turn, may be defined as the development and implementation of boundary conditions that create selective pressures, by acting upon private corporations, for the evolution of technologies that support the achievement of sustainability.

If this is the case, we have reached an important understanding. Corporations may indeed be evolving in response to changes in the boundary conditions affecting them. The changes result from increased anthropogenic environmental perturbations and concomitant regulatory developments. We should not expect otherwise. However, private firms should not be fundamentally redefined and, to the extent public policies have created trends to do so, must be carefully evaluated and monitored. Meanwhile, the public policy challenge lies not in traditional environmental regulation or increasingly stringent end-of-pipe regulation, but in the establishment of boundary conditions that encourage private firms and the economy as a whole to self-organize in a sustainable structure.

NOTES

1. The terms "corporation" and "firm" as used in this paper refer to private, for-profit entities established under various state and national general incorporation statutes, as opposed to nonprofit organizations and governmental entities.
2. There is a large literature on whether corporations should be redefined to include public-interest factors explicitly among their goals or whether they are assuming responsibilities—such as the provision of health care and support for older citizens or the conduct of international trade and control of global financial structures—formerly provided directly or indirectly by the nation-

state. The question of whether firms, especially large transnationals, are participating in the devolution of the nation-states' responsibilities to others, including both local and international political units, is fascinating but far beyond the scope of this paper. Nonetheless, the trends discussed in this paper can be seen as elements of what appears to be currently accelerating shifts of power and responsibilities among political and economic entities at all levels.

3. Any economy consists of a number of agents—suppliers, consumers, regulators, etc. Additionally, some interesting work is being done on the self organization of loosely linked groups of firms that form frequently successful and innovative industrial districts, such as Silicon Valley in the United States, or the collection of textile firms near Florence, Italy, known as "The Third Italy." This discussion, however, is limited to the class of agents identified as for-profit private corporations, primarily because any broader discussion would be far too complex for a short paper. Note that in any such analysis, only a limited class of agents is being considered and that these agents both modify and are modified by—coevolve—all other elements of the system.
4. Such a substitution of inputs is already evident in the transportation sector, where advanced computing technology, on-board electronic systems, sensors, and other information systems are being used to meet increasingly stringent environmental constraints. See, generally, Auzins and Wilhelm, 1994; The Economist, 1994.
5. Note that this is a separate issue from the so-called green accounting problem, arising when management accounting systems include environmental costs and liabilities in overhead, thus reducing the ability of managers to identify and reduce such costs and the associated environmental impacts (Macve, this volume; Todd, 1994). Social costs are not included in management accounting systems.
6. Not in all cases. Note, for example, the structure of postconsumer take-back in the automobile industry in the United States: Some 65 to 70 percent of automobiles by weight are recycled, and many subassemblies are refurbished (rebuilt) and placed back into commerce without any explicit control mechanism. A wide variety of parts dealers, junkyards, scrap operators, and secondary smelters have formed a very effective recycling system, organized only through mutual economic self-interest (Klimisch, 1994). The self-organizing properties of complex systems cannot be overlooked, but more study is required to learn what conditions favor the evolution of such behavior. Why are white goods or electronic items not similarly recycled? What boundary conditions might result in the self-organization of a similar system for such products? More pessimistically, what changes in current policies might result in the disruption of an already fairly efficient demanufacturing operation?
7. The need for firms to integrate technology and environment throughout their operations and recognize environmental issues as strategic for the firm is arising just as the shift from regional and nation-state to global economic competition (at least among developed countries) and from internal management based on mass manufacturing paradigms to information-based non-hierarchical models is occurring. Environmental issues then become one of several forces fostering radical change in the firm, and such change is easier when more than one driver is at work. In some ways, the process appears analogous to punctuated evolution, but consideration of whether this is only a superficial similarity or evidence of some deeper similarity based on principles of behavior of complex systems is beyond the scope of this paper.
8. The reader will have noted, possibly skeptically, that this paper assumes that sustainability can be achieved without social, economic, or natural upheavals. This is, indeed, only an assumption, as the author is not aware of any data that convincingly support such an optimistic conclusion. However, it seems best in this matter to adhere to the philosophy of pragmatism espoused by William James and act as if sustainability is achievable, lest, by the failure to act, the opposite become a self-fulfilling prophecy.

REFERENCES

Allenby, B. R. 1992. Design for Environment: Implementing Industrial Ecology. Ph.D. dissertation for Rutgers University, Princeton, N.J.

Allenby, B. R. 1993. Industrial ecology: The materials scientist in an environmentally constrained world. MRS Bulletin 17(3):46–51.

Allenby, B. R. 1994. Industrial ecology gets down to earth. IEEE Circuits and Devices 10:24–28.

Allenby, B. R., and W. Cooper. 1994. Understanding industrial ecology from a biological systems perspective. Total Quality Environmental Management 3(3):343–354.

American Electronics Association (AEA). 1993. The Hows and Whys of Design for the Environment. Washington, D.C.: AEA.

Auzins, J., and R. V. Wilhelm. 1994. Automotive Electronics—Getting in Gear for the 90's and Beyond. IEEE Circuits and Devices 10:14–18.

Costanza, R., ed. 1991. Ecological Economics. New York:Columbia University Press.

Daly, H. E., and J. B. Cobb, Jr. 1989. For the Common Good. Boston: Beacon Press.

Dertouzos, M. L., R. K. Lester, R. M. Solow, and the M.I.T. Commission on Industrial Productivity. 1989. Made in America: Regaining the Productive Edge. New York: Harper Perennial.

Drucker, P. F. 1988. The coming of the new organization. Harvard Business Review January–February:45–53.

The Economist. 1994. New age transport: trains, planes and automobiles. December 25–January 7:96–98.

Elkins, P. 1993. 'Limits to growth' and 'sustainable development': Grappling with ecological realities. Ecological Economics 8:269–288.

Friedman, M. 1962. Capitalism and Freedom. Chicago: University of Chicago Press.

Graedel, T. E., and B. R. Allenby. 1995. Industrial Ecology. Princeton, N.J.: Prentice-Hall.

Keoleian, G. A., and D. Menerey. 1993. Life Cycle Design Guidance Manual: Environmental Requirements and the Product System, EPA/600/R-92/226. Washington, D.C.: U.S. Environmental Protection Agency.

Klimisch, R. L. 1994. Designing the modern automobile for recycling. Pp. 165–170 in The Greening of Industrial Ecosystems, B. R. Allenby and D. J. Richards, eds. Washington, D.C.: National Academy Press.

Netherlands Company for Energy and the Environment. 1992. The Netherlands Institute for Public Health and Hygiene (RIVM), and The Netherlands National Research Programme for Recycling of Waste Materials, Methodology for Environmental Life Cycle Analysis: International Developments, Contract Number 8283.

Organization for Economic Co-Operation and Development. 1992. Technology and Environment: Government Policy Options to Encourage Cleaner Production and Products in the 1990's. OCED/GD(92)127. Paris.

Rosenberg, N., and L. E. Birdzell, Jr. 1990. Science, technology and the Western miracle. Scientific American 263(5):42–54.

Scherer, F. M. 1980. Industrial Market Structure and Economic Performance. Boston: Houghton Mifflin.

Society of Environmental Toxicology and Chemistry (SETAC). 1991. A Technical Framework for Life-Cycle Assessments. Washington, D.C.: The SETAC Foundation.

Stahel, W. R. 1994. The utilization-focused service economy: Resource efficiency and product-life extension. Pp. 178–190 in The Greening of Industrial Ecosystems, B. R. Allenby and D. J. Richards, eds. Washington, D.C.: National Academy Press.

Todd, R. 1994. Zero-loss environmental accounting systems. Pp. 191–200 in The Greening of Industrial Ecosystems, B. R. Allenby and D. Richards, eds. Washington, D.C.: National Academy Press.

Vagts, D. F. 1973. Basic Corporation Law. Mineola, N.Y.: The Foundation Press, Inc.

Examples of Environmental Design and Management

The Industrial Green Game. 1997. Pp. 117–123.
Washington, DC: National Academy Press.

The Industrial Symbiosis at Kalundborg, Denmark

HENNING GRANN

The concept of sustainable development is being widely referred to by politicians, industrialists, and the press. Although there is agreement in principle about the meaning of this concept, there are many and differing opinions as to what it means in practice and how the concept should be translated into specific actions.

The industrial symbiosis project at Kalundborg, Denmark (100 kilometers west of Copenhagen, population of approximately 15,000), is a model of environmental sustainability. It provides a vision of what is possible. The project has attracted a good deal of international attention, notably by the European Community, and been awarded several environmental prizes.

The symbiosis project, however, is not the result of a careful environmental planning process. It is rather the result of a gradual cooperative evolution of four neighboring industries and the Kalundborg municipality. Although begun by chance, the project has now developed into a high level of environmental consciousness in which the participants are constantly exploring new avenues of environmental cooperation.

What is industrial symbiosis? In short, it is a process whereby a waste product in one industry is turned into a resource for use in one or more other industries. It is the essence of a well-functioning ecosystem. The Kalundborg experience shows that cooperation among different industries in the use of waste increases the viability of the industries. At the same time, the demands from society for resource conservation and environmental protection are met.

Four industrial facilities—a power plant, an oil refinery, a plaster-board manufacturing plant, and a biotechnology production facility—and the local municipality participate in the Kalundborg symbiosis.

- The power plant, Denmark's largest, is owned by Asnæsværket. It is coal fired, has a capacity of 1,500 megawatts (mW), and employs about 600 people.
- The oil refinery, Denmark's largest, is owned by Statoil. The refinery has a capacity of about 3 million tons per year (tons/yr) and is being expanded to a capacity of 5 million tons/yr. It employs about 250 people.
- The plaster-board manufacturing plant, owned by Gyproc a.s., produces about 14 million square meters per year of plaster-board for the building industry. It employs about 175 people.
- The biotechnology facility is owned by Novo Nordisk. The company produces about 45 percent of the world market of insulin and about 50 percent of the world market of enzymes. In addition, the company produces substantial quantities of growth hormones and other pharmaceutical products. Novo Nordisk operates in several countries, but the Kalundborg plant, with 1,100 employees, is the company's largest production site.
- The Kalundborg municipality controls the distribution of water, electricity, and district heating in the Kalundborg city area.

DEVELOPMENT OF THE SYMBIOSIS

The symbiosis—or cooperative use of waste heat and materials—was not planned. The relationships that developed and are shown in Figure 1 evolved over a period of more than 20 years. A chronology of key events follows.

1959 The principal player, Asnæsværket, was started up.

1961 Tidewater Oil Company commissioned the first oil refinery in Denmark, and a pipeline was constructed from Lake Tissø to provide water for its operation. (The refinery was taken over by Esso in 1963 and acquired by Statoil in 1987 along with Esso's Danish marketing facilities.)

1972 Gyproc established a plaster-board manufacturing plant. A pipeline to supply excess refinery gas was constructed from the refinery to Gyproc facilities.

1973 The Asnæsvæket power plant was expanded. To meet increased water demand, an agreement was reached with the refinery to build a connection to the Lake Tissø-Statoil pipeline.

1976 Novo Nordisk started delivering biological sludge to neighboring farms by tank truck.

1979 The power plant started supplying fly ash (until then a troublesome waste product) to cement manufacturers such as Aalborg Portland located in northern Denmark.

1981 The Kalundborg municipality completed a district heating distribu-

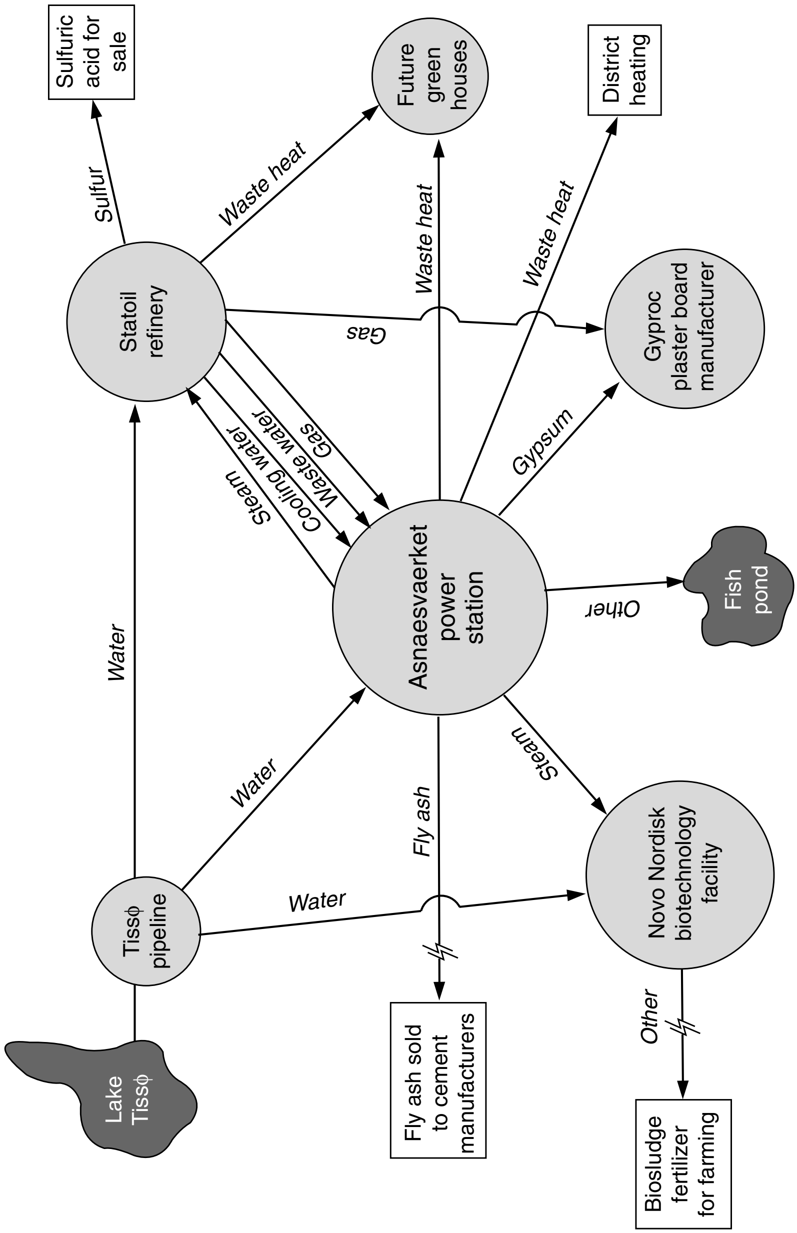


FIGURE 1 The Kalundborg symbiosis.

tion network within the city of Kalundborg utilizing waste heat from the power plant.

1982 Novo Nordisk and the Statoil refinery completed the construction of steam supply pipelines from the power plant. By purchasing process steam from the power plant, the companies were able to shut down inefficient steam boilers.

1987 The Statoil refinery completed a pipeline to supply its effluent cooling water to the power plant for use as raw boiler feed water.

1989 The power plant started to use the waste heat from its salt cooling water (+7–8°C) to produce trout and turbot at its local fish farm.

1989 Novo Nordisk entered into an agreement with the Kalundborg municipality, the power plant, and the refinery to connect to the water supply grid from Lake Tissø to meet Novo's rising demand for cooling water.

1990 The Statoil refinery completed the construction of a sulphur recovery plant. The elemental sulphur being recovered is being sold as a raw material to a sulfuric acid manufacturer located in Fredericia on the mainland of Yetland in Denmark.

1991 The Statoil refinery commissioned the building of a pipeline to supply biologically treated refinery effluent water to the power plant for cleaning purposes and for fly-ash stabilization.

1992 The Statoil refinery commissioned the building of a pipeline to supply refinery flare gas to the power plant as a supplementary fuel.

1993 The power plant completed a stack flue gas desulfurization project. This process converts sulphur dioxide (SO_2) flue gas to calcium sulphate (or gypsum) which is sold to the Gyproc plaster-board plant, where it replaces imported natural gypsum. The new raw material from the power plant has increased the quality of plasterboard that is manufactured.

Future The construction of green houses, to be supplied with residual heat, is being considered by the power plant and the refinery.

ACHIEVEMENTS OF THE SYMBIOSIS

The annual material and energy flows of the four industrial partners in the symbiosis are shown in Table 1. The reductions in resource consumption, emissions, and waste in this symbiotic relationship are shown in Table 2. The most significant achievements of the industrial symbiosis cooperation at Kalundborg are that:

- there have been significant reductions in energy consumption and coal, oil, and water use;

TABLE 1 Annual Materials and Energy Flows of the Four Industrial Partners in the Kalundborg Symbiosis

Industrial Partner	Production	Emissions	Resource Consumption
Asnæsværket	Electricity: 300,000,000 kWh	CO_2: 4,300,000 tons	Water: 400,000 m^3 (treated)
	Process Steam: 355,000 tons	SO_2: 17,000 tons	100,000 m^3 (raw)
	District heating: 700,000 GJ	NO_x: 14,000 tons	700,000 m^3 (re-used) cooling water from Statoil
	Fly ash: 170,000 tons		500,000 m^3 (re-used waste water from Statoil)
	Fish: 200 tons		Coal: 1,600,000 tons
	Gympsum: 80,000 tons		Oil: 25,000 tons
			Gas: 5,000 tons (flare gas from Statoil)
Statoil Refinery	3,200,000 tons of a full range of fuel products	SO_2: 1,000 tons	Water: 1,300,000 m^3 (raw)
		NO_x: 200 tons	50,000 m^3 (treated)
		Waste Water: 500,000 tons	Steam: 140,000 tons (from Asnæsværket)
		Oil: 1.8 tons	189,000 tons (own waste heat)
		Phenol: 0.02 tons	Gas: 80,000 tons
		Oily Waste:[a] 300 tons	Oil: 8,000 tons
			Electric: 75,000,000 kWh
Gyproc	14,000,000 m^2 of plaster-board	N/A	Gypsum: 80,000 tons (from Asnæsværket)
			33,000 tons (natural gypsum)
			8,000 tons (from recycling)
			Cardboard: 7,000 tons
			Oil: 3,300 tons
			Gas: 4,100 tons
			Water: 75,000 tons
			Electric: 14,000,000 kWh
Novo Nordisk	Industrial enzymes	Waste Water: 900,000 m^3	Water: 1,400,000 m^3 (treated)
	Insulin	COD: 4,700 tons	300,000 m^3 (raw)
	(Production figures N/A)	Nitrogen: 310 tons	
		Phosphorus: 40 tons	Steam: 215,000 tons
			Electric: 140,000,000 kWh

kWh = kilowatt-hours; GJ = gigajoule; m^2 = square meters; m^3 = cubic meters

[a]The oily waste is biologically degraded at Statoil's sludge treatment facilities.

TABLE 2 Results of the Kalundborg Symbiosis

Sources of Reduction	Total Reductions (tons/yr)
Resources	
Oil	19,000
Coal	30,000
Water	1,200,000
Emissions	
CO_2	130,000
SO_2	25,000
Waste	
Fly ash	135,000
Sulfur	2,800
Gypsum	80,000
Nitrogen from biosludge	800
Phosphorus from biosludge	400

- environmental impacts have been lessened through reductions in SO_2 and CO_2 emissions and improved quality of effluent water; and
- traditional waste products such as fly ash, sulphur, biological sludge, and gypsum have been converted into raw materials for production.

The symbiosis has created a positive image of Kalundborg as a clean industrial city. Perhaps most significantly, there has been a gradual development of a systematic environmental "way of thinking" that may be applied to many other industrial settings and which may be used in planning new industrial complexes. The effective symbiosis at Kalundborg has a number of important characteristics (Box 1).

FUTURE DEVELOPMENTS

At Kalundborg, all future projects and/or process modifications will be considered for potential inclusion in the industrial symbiosis network. A number of interesting ideas have been identified for further study. In the meantime, the Kalundborg experience offers a practical model to examine ways to minimize the environmental impact from existing and new industrial complexes.

Traditionally, increase in industrial activity implies an almost linear increase in the load on the environment. The industrial symbiosis concept suggests that this need not necessarily be so. Indeed, under this model, increased industrial

BOX 1 Characteristics of Kalundborg Symbiosis

- The participating industries are different but benefit mutually from utilizing each other's waste.
- The individual industry agreements are based on commercially sound principles.
- Environmental improvements, resource conservation, and economic incentives go hand in hand.
- The development of the symbiosis is voluntary but occurs in close cooperation with government authorities.
- Short physical distances between participating plants are advantageous.
- Short "mental" distances are equally important. Visions of possible beneficial links are critical.
- Mutual management understanding and cooperative commitment is essential.
- Effective communication between participants is required.
- Significant side benefits are achieved in other areas, such as safety and training.

activity may lead to fewer environmental impacts. The key lies in carefully selecting processes and combining industries that together may effectively utilize waste materials as production inputs and thus reduce environmental impacts. Kalundborg is an ideal situation that will be difficult to duplicate. Nevertheless, Kalundborg provides a vision of what can be achieved locally, regionally, and globally.

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Environmental Prioritization

INGE HORKEBY

Volvo's environmental initiatives, which began in the early 1970s, have evolved into a holistic approach to considering the environmental impacts of its products. In essence, the company has adopted a total systems approach to reduce the environmental impact of its products and production processes. This means that all aspects of a product's life cycle, from development through production and everyday use to disposal and recycling, are considered in addressing environmental concerns.

This total systems approach led Volvo in 1989 to initiate development of a sophisticated life cycle analysis system to examine the environmental impacts of materials and products. The system, known as Environmental Priority Strategies in Product Design (EPS), was developed collaboratively with the Swedish Environmental Research Institute and the Federation of Swedish Industries.

Internationally, two trends prompted the development of a tool to help select environmentally preferable materials. The first was the development of the life cycle assessment (LCA) concept from simple inventories of materials inputs and outputs into more sophisticated decision-support tools that also assessed associated environmental impacts. The Society for Environmental Toxicology and Chemistry (SETAC) emerged as a forum for international scientific exchange on LCA issues. Standard-setting organizations, such as the International Standards Organization and Comite European de Normalization, and business consortia, such as International Chamber of Commerce, started to show interest in LCA although most of the LCA studies conducted were (and continue to be) conducted on simple products of low design (packaging such as cans) or simple chemical compounds. Volvo wondered how such a tool might be used by a producer of a complex product such as a car.

The second force behind the development of EPS was the emergence and acceptance of the sustainability concept in governments and the scientific community. United Nations Environment Program director Mustafa Tolba's statement, "The 1990s will witness enormous changes in most sectors of society, but in almost none will they be as evident as in industry and environment and the new relationship that has formed between them," captured the trend as it affected industry. In the quest for sustainability, countries began experimenting with creating a "green" gross national product that would include an accounting of the state of the environment. It seems likely that there would be a monetary evaluation of the state of the environment in the future. Such a valuation of the state of the environment meant that any activity that affected the environment could also be valued on the basis of its impact. The implications of these trends to the firm are uncertain. It is clear, however, that it would be useful to know and understand a firm's environmental impacts.

VOLVO'S DESIGN FOR THE ENVIRONMENT APPROACH

Volvo's response to these trends builds on its 1983 efforts to design a low-weight component car. Many new ideas were tested in the process of designing a low-energy-consuming car. However, it was not easy to evaluate the environmental implications of different designs. For example, a low-weight material might have been produced with a lot of energy but its contribution to a low-weight vehicle implied a potential for reducing fuel consumption during vehicle operation. When Volvo launched the Environmental Concept Car in 1992, Volvo designers wanted a tool that could aid in the selection among design alternatives.

Designers routinely handle several different criteria in their design process. The product definition gives the designer many things to consider. The success or failure of the design often hinges on related product attributes that may be of equal importance. Examples of such design elements include design for quality, for safety, against corrosion, for manufacturability, for assembly, and for serviceability.

To the designer, design for the environment (DFE) would be another design element. Volvo's aims were to fit DFE as a module into the design element list that guides company designers and to develop a tool for environmentally prioritizing product designs. An equally important aspect of the car design process is the degree to which computers are used. Modern car design teams use computer-aided design software that can incorporate standard component modules.

Volvo designers required a DFE tool that aggregated environmental impacts and was

- computer based;
- flexible;
- transparent;

- reasonably fast;
- capable of carrying out multiple analyses;
- able to adjust to changes in best practice and best available technique;
- compatible with environmental inventory tools;
- product, processes, and industry oriented;
- capable of integrating new scientific findings; and
- transparent or neutral in assigning values to environmental attributes.

DEVELOPMENT OF THE EPS SYSTEM

Volvo designers, the Swedish Federation of Industries, and the Swedish Environmental Research Institute began discussing ways to develop a tool that could help guide decisions about environmental preferability. The tool was to be a compass, guiding appropriate environmental choices, not necessarily providing a definitive answer. During 1990, the first version of a tool (EPS-system, version 1.0) was developed (Ryding and Steen, 1991).

A top-down approach was used to develop the system. The first question posed was, "What decisions do we need to make"? The last was, "What knowledge base do we need"? Relatively little attention was paid to well-known factors. Most of the work was done on factors such as certain environmental issues and the subjective values placed on environmental goods that could be barriers to the use of the system.

To examine the use of the system and to develop it further, a second phase, the Product Ecology Project, was initiated. The project was led by the Swedish Federation of Industries and included the participation of 15 Swedish companies, Chalmers University of Technology, and the Swedish Environmental Research Institute.

The second phase included the development of a newer version of the EPS system (Steen and Ryding, 1992), which is being tested by several companies. The development of the system was funded mainly by the Swedish Waste Research Council. The council carried out an international evaluation of the system concept in September 1993. The experiences from those activities will be included in the EPS system design.

The system structure has been published in several articles and reports, but the databases and the software are still being developed and are not fully available for public use. The data for particular materials have to be proprietary to avoid a lot of unnecessary inconvenience for their manufacturers. For development purposes, however, less precise data have been used.

THE EPS SYSTEM

The EPS system assesses environmental impacts in terms of ecological and health consequences. It provides an opportunity to enumerate and assess envi-

TABLE 1 Factors Considered in Calculating Environmental Indices

Factor	Meaning
Scope	General impression of the environmental impact
Distribution	Extent of affected area
Frequency or Intensity	Regularity and intensity of the problem in the affected area
Durability	Permanency of the effect
Contribution	Significance of 1 kilogram emission of the substance in relation to the total effect
Remediability	Relative cost to reduce the emission by 1 kilogram

Environmental Index = Scope X, Distribution X, Frequency or Intensity X, Durability X, Contribution X, Remediability X

ronmental impacts of various human activities, such as emissions, energy use, raw materials use, and land use, at every material and product life stage before these data are aggregated and finally evaluated. Both basic assessments of values of environmental qualities as well as changes in these values resulting from human activities are estimated.

The EPS system allows bookkeeping of environmental impacts. The principle tools of the EPS system are the definition of so-called environmental load indices for natural resource and energy use and for pollutant emissions. On the basis of these inputs, environmental indices for materials and processes are calculated (Table 1).

The background information originates from an LCA-based inventory of materials and processes under study. Using the environmental load indices for materials and processes, an environmental load unit (ELU) per kilogram of any substance is calculated by multiplying the environmental index by the amount of substance released to the environment for the activity, process, or product life cycle under study. These can then be aggregated.

The results of this analysis are grouped in various levels of aggregation suitable for any use. For instance, the environmental impact from production of steel can be expressed as a value relative to the impact from another activity. Any such number may be broken down into its components for further analysis, and the user can choose the analysis's level of complexity. Because uncertainty is inherent in much environmental data and many analyses, another necessary aspect of the EPS methodology is its use in sensitivity analysis. Sensitivity analysis responds to the need to know and allows the determination of how any quantity entered into the calculations influences the decision at hand. What data or change in environmental impacts would change the ELU value? Because most decisions are based on the comparison between two options, the measure of sensitivity for a certain quantity, X, is chosen to be the ratio between the standard deviation of X and the change in X necessary to alter the priority of the options.

For an error analysis to be made, the figure entered into the system must be expressed in terms of best estimate and an error function. The error function is, in most cases, assumed to be a log-normal distribution and it is described by the geometric standard deviation.

GENERAL CONSIDERATIONS

There are many different ways to evaluate environmental impacts arising from such diverse concerns as depletion of resources or emissions. No system, even if it is developed systematically, is likely to be infallible, however.

Today, only a couple of methods are published and available for evaluating different emissions on the basis of existing national targets for emission reductions. One is the effect category method (Baumann et al., 1992b; McKinsey & Company, 1991). This method evaluates data from the life cycle inventory (Table 1) with respect to their contribution to relevant environmental effects, called effect categories. The Chalmers University of Technology in Sweden has refined the method so that the effects also reflect the impact of political decisions and critical environmental loads. Another method, the ecoscarcity method, was developed by the Environmental Agency in Switzerland (Ahbe et al., 1990; Baumann et al., 1992a). Ecological scarcity is defined as the relation between the total environmental load on a defined geographical area and the critical load that area can withstand. The critical load was originally defined in terms of ecological limits. The Swedes have defined the critical load in terms of environmental targets set by law. However, the EPS system does not use national targets; it estimates the environmental ecological consequences.

The Swedish Parliament has decided that the objective of the Swedish environmental policy is to protect human health, preserve biological diversity, maintain a long-term husbandry of natural resources, and protect the natural and cultural landscape. Five environmental safeguard subjects have been defined (Table 2).

In refining the EPS system, these safeguard subjects are chosen to describe and measure all impact types in the environment of interest. It is, however, possible to

TABLE 2 Objectives of the Swedish Environmental Policy

Safeguard Subject	Valuation Principle
Biodiversity	Society's cost for protecting biodiversity
Human Health	Society's cost for reducing excess deaths caused by various risks, and people's willingness to pay to avoid diseases, suffering, and irritation
Production	Organization for Economic Cooperation and Development market prices
Resources	Impact on the other safeguard subjects when restoring the resource
Aesthetic Values	People's willingness to pay

test other valuations in the EPS system, if necessary. The EPS method sets a value to a specific change in the environment (especially in terms of the safeguard subjects) and estimates what contribution a certain resource depletion, emission, or other activity will give to this value for this change in the environment

This exercise results in a value, the ELU. When the value is expressed as ELU per kilogram or ELU per some other unit, it is referred to as an environmental load index. The environment load index can be used to compare various materials and aggregate materials with one another.

Practical Use

One of the weaknesses of LCA is its lack of practical application except in very special situations. The main objective in developing the EPS system has been to create a tool for use in everyday design situations in which one value expresses the total environmental impact of a material or process. The EPS uses a value that is not equal to money but can be compared with monetary value so that the potential environmental impact of a product can be quantified. In many cases, the answer obtained by using the EPS system requires further, more profound analysis. The system is designed so that users can access the calculations and basic data used to obtain any value. Users can choose the level of complexity and then run a sensitivity analysis to determine how changes in valuations and estimations may alter a design decision. Often, there are points in the product-development process where environmental issues have to be handled in different ways—from a fast screening of ideas to a more thorough analysis of the final concept.

Implementation

The development of EPS, which enables the car designer to incorporate the environmental properties of a product from the initial development stage, has continued since it was initiated in 1989. As the initiator, Volvo has taken an active part in developing the system.

The key element of EPS is the environmental index. This index enables the adverse effects of emissions and the use of natural resources to be quantified. A unique feature of the system is that different factors can be weighed together to produce a single value describing the total environmental load. This makes it possible to create environmental indices not only for pure materials, but also for processes or parts of processes of interest in different design options, such as casting, forging, rolling, riveting, chromium plating, zinc plating, powder plating, and painting.

Hundreds of indices of interest have been created. The Product Ecology Project, which brought together several industry sectors, made the creation of these indices possible. The best source of information about the environmental impact of material production and processes is, of course, those in the industries making the materials and using the processes.

For many years, Swedish industry conducted environmental impact analyses to obtain environmental permits from government authorities. As of 1991, as prescribed by law, companies large enough to need an environmental permit are required to provide yearly environmental reports that include environmental impact information. Information about the environmental impacts is publicly available, and industry is less reluctant than before to reveal the details of the emissions to those other than the authorities. The information in the environmental reports is insufficient to create environmental indices for the EPS system. More detailed information of the emissions, especially from various parts of operations, is needed. The Product Ecology Project and the cooperation between the 15 Swedish industrial firms enabled more detailed information to be used, which facilitated development of the inventory used in the EPS.

The EPS system has been tested in important projects such as the Volvo Environmental Concept Car and the development of the new range of heavy-duty trucks. These tests have been extremely important in determining best ways to improve the system.

Volvo is now deciding on the next step in implementing the EPS system. The challenge the company faces is to find the best level for introducing EPS within its design organization. One solution is to use the EPS system in groups devoted to the design of aggregated assembled products.

The main advantage of using a system such as EPS is that it forces the designer to incorporate concerns at an early stage of forming new products. This step is far more important than the specific data that the system produces. EPS system data are not absolute values that can be used separately. The system should be used to compare different design alternatives and to ensure that good decisions are made. The detailed analysis can be used to assess where in the life cycle the worst environmental impact occurs and to determine what variables are crucial to making alternative design decisions.

Very different environmental impacts are compared in the system through a valuation process. This step is more subjective than inventorying data and can be a cause of grave concern. However, total life cycle analysis sooner or later requires that value judgments be made.

Clearly, the valuation of different environmental impacts is never going to be accepted universally. Values may vary between countries, between times, and among individuals. Therefore, it is important to have a system that can adjust for such changes quite easily. The EPS system is flexible enough to do that and is a practical tool that can be used in a design process. It is an important tool but not the only element in design-for-environment strategies.

The EPS system also can never substitute for other company procedures that are effective in continuous improvement of environmental performance. Often, design constraints are contained in a company's environmental policy, objectives, and programs. Communication between the designers and company specialists (such as environmental chemists and technologists) is a vital source of information for the design phase and cannot be replaced by an expert system.

Introducing a system such as EPS without a strong organization of environmental specialists within the company to back it up could be counterproductive. EPS could give a false sense of security in the absence of discussions and questions that arise when the system is used to test and environmentally assess different design alternatives.

The EPS system is not a troubleshooter, it merely provides decision-makers with a summary of complicated patterns of energy, materials, and pollutant emissions in a manageable, easily understood, and reviewable form. Even the best LCA study needs a competent end user to make optimal use of the sensitivity and error analyses and to interpret the outcome in a way that matches other decision making inputs (such as economic and technical factors). The complexity of nature raises questions about efforts to model its structure and function as well as the merits of using the results of such models. It is, therefore, more a question of ambition and will than indisputable data inputs and comprehensive coverage of all data to carry out LCA and other approaches for assessing environmental consequences of human activities. At the very least, even a weak LCA-based system can increase the interest in a systems approach to addressing future environmental problems and to involving a wider community of stakeholders.

REFERENCES

Ahbe, S., A. Braunschweig, and R. Muller-Wenk. 1990. Methodik füer Oekobilanzen auf der Basis Oekologischer Optimierung Schriftenreihe Umwelt nr 133. Bern: The Environmental Agency in Switzerland (BUWAL).

Baumann, H., C. A. Bostrom, T. Ekvall, E. Eriksson, T. Rydberg, S. O. Ryding, B. Steen, G. Svensson, T. Svensson, and A. M. Tillman. 1992a. Miljöbedömning av förpackningsutredningens slutsatser. FoU nr 71. Stiftelsen REFORSK, Malmö.

Baumann, H., T. Ekvall, E. Eriksson, M. Kullman, T. Rydberg, S. O. Ryding, B. Steen, and G. Svensson. 1992b. Environmental Comparison between Recycling/Re-use and Incineration/Landfilling. (In Swedish.) FoU Report No. 79, REFORSK.

McKinsey & Company. 1991. Integrated Substance Chain Management, Appendix. Commissioned by Association of Dutch Chemical Industry (VNCI). September.

Ryding, S. O., and B. Steen. 1991. The EPS System. IVL report No. B 1022. Göteborg, Sweden: Swedish Environmental Research Institute.

Steen, B., and S. O. Ryding. 1992. The EPS Enviro-Accounting Method: An Application of Accounting Principles for Evaluation and Valuation of Environmental Impact in Production Design. IVL Report B 1080. Göteborg, Sweden: Swedish Environmental Research Institute.

The Industrial Green Game. 1997. Pp. 132–147.
Washington, DC: National Academy Press.

Improving Environmental Performance Through Effective Measurement

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In general, business in the 1970s was strongly driven by concerns about quality. In the 1980s, price and innovation were major drivers along with quality. In the 1990s, these driving forces are still in place; however, companies' environmental performance has emerged as a major factor that can affect short- and long-term business success. Environmental compliance audits are but one small measure of a company's overall environmental performance. An effective set of performance measurement tools is required to develop information for company managers and other stakeholders. Development of well-defined and effective measurement tools for environmental performance is still in its infancy, with only a small number of companies having made significant progress to date.

Improvements in environmental performance[1] do not occur abruptly. Success requires a permanent commitment to environmental leadership, including but not limited to the following elements: an overall philosophy and corporate culture established and demonstrated by senior management; acceptance of and commitment to the overall philosophy, governing principles, and policies by all employees; clear standards of performance and operating procedures; technologies and technical resources qualified to meet challenges in a competitively advantageous manner; well-educated and well-trained staff at all levels; and systems to measure and evaluate current performance, identify areas for continuous improvement, and incorporate these into new performance standards and goals.

Improving environmental performance requires successful implementation of all of the above-described leadership elements. However, a system to measure and evaluate environmental performance is certainly a key element and one that companies have been struggling with over the past several years.

ENVIRONMENTAL PERFORMANCE EVALUATION[2]: OVERVIEW

Compliance with applicable laws and regulations is a basic company (facility) operating requirement that must be achieved through line management and confirmed by audits. In the environmental area, there is never a lack of data. However unless those data are translated into useful information, they are nothing but a huge set of numbers useless for setting priorities or making decisions. The overriding goal for effective environmental performance measurement systems should not be on compliance; rather, it should be to gather information (not data) for use in identifying opportunities for continuous improvement. Herein lies the linkage between environmental measurement systems and any quality improvement process, which can be paraphrased as total quality environmental management (TQEM).

Most companies are just beginning to implement TQEM programs. Useful environmental performance measurements require several years of information because TQEM measures progress or continuous improvement rather than relying on absolute measures of quality (FitzGerald, 1993). Most companies are still developing and testing their environmental measurement systems. However, there have been several recent conferences on the subject, and companies are beginning to share their experiences.

The first step in developing an effective measurement system is to identify the information needed. By using TQM principles, this must be derived from the requirements of the customers, both internal and external. Wells et al. (1993) propose that effective environmental measurement systems collect information from three interrelated perspectives: process measures and improvements, environmental results, and customer satisfaction (Figure 1).

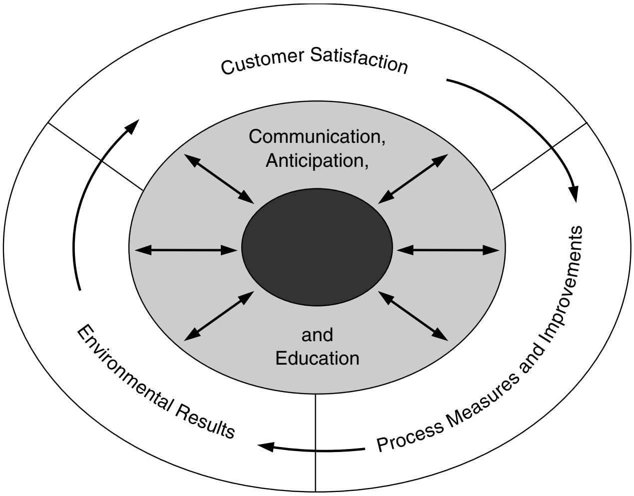

FIGURE 1 Customer requirements drive environmental measurement. SOURCE: Wells et al., 1993.

Process measures and improvements assess the effectiveness of existing management systems to meet not only current requirements but also anticipate future requirements; this information is typically collected through the audit process. Environmental results evaluate the effectiveness of programs on incremental improvement; this information is typically generated through self-reporting by facilities. Customer satisfaction measurements assess whether changes or improvements are valued by stakeholders. It is important to recognize that corporations have many stakeholders, including the general public, stockholders, employees, senior management, regulatory authorities, raw materials suppliers, and purchasers of products. Although it may be quite straightforward to understand the direct requirements of several of these stakeholders (e.g., current compliance requirements of regulatory authorities or a challenge from senior management to reduce waste by a certain percentage per year), obtaining information from other customers can be more challenging, as illustrated later in this paper by Ciba-Geigy (Ciba) efforts to measure the environmental satisfaction of its customers.

No single measurement will accurately reflect a company's overall environmental performance. A properly selected set of measures, used as a system, is required to provide the types of information necessary for decisions and action plans. Table 1 lists a number of measures, what they measure, as well as their general advantages and disadvantages.

Although the toxic release inventory (TRI) system has been valuable in raising the environmental consciousness of U.S. corporations, some of its measurement protocols do not reflect actual releases to the environment. For example, a facility whose wastewater contains highly biodegradable materials will not have a "measured" release if it has an on-site treatment plant but would show a release according to TRI if the wastewater is piped to a publically owned treatment works. For these two cases, there is no difference as to what is actually released to the environment, but one is measured as a release whereas the other is not.

Most of the systems listed in Table 1 do not consider efficient use of raw materials, most notably raw water usage. Although the supply of usable water is generally not yet critically limiting, reduced availability of this resource is becoming apparent, and attention to this issue is appropriate to prevent it from becoming a significant problem. Also, most of the systems listed in Table 1 do not recognize the domino effects of addressing environmental issues. For example, hydrochlorofluorocarbons (HCFC) substitutes for chloroflurocarbons require more energy to achieve the same results, producing secondary emissions of greenhouse gases (e.g., carbon dioxide). An alternative chloroflurocarbon substitute (ammonia) has good energy efficiency but higher toxicity and would require enhanced safety considerations.

STRATEGIC ENVIRONMENTAL AUDITING

The term "audit" is often misused in that it is used to refer to ordinary controls or inspections that are an integral part of any manager's or supervisor's

TABLE 1 Measures of Environmental Performance

Measure	What It Measures	Advantages	Disadvantages
Permit Compliance	Compliance with applicable permits expressed as exceeding permit limits.	An essential measure—customers will look first to your compliance with permits	Taken alone, a narrow measure indicating that you are doing only what is required.
Toxic Release Inventory (TRI) Chemical Releases	Over 300 chemicals subject to release annual reporting requirements under SARA[a] Section 313.	Information on releases is widely available to the public; an effective way to communicate performance.	Does not cover all important chemicals or industries; focuses on release volume without accounting for differences in toxicity.
33/50 Chemicals	A subset of 17 of the TRI chemicals identified by the Environmental Protection Agency as priority candidates for voluntary reductions in releases by industry.	A more refined list of chemicals than TRI; companies participating in the 33/50 program and meeting goals will receive public credit.	Leaves out many important chemicals; not clear that a company not participating in the 33/50 program will receive special credit for these reductions.
Clean Air Act Toxics	189 chemicals listed in the Clean Air Act as air toxics subject to maximum achievable control technology (MACT) standards.	MACT standards will be extremely costly to meet. By reducing or eliminating releases, you avoid very high future costs.	Taken alone, like TRI, not a full measure of environmental performance; focuses only on air; creates risk of shifting problem from air to other media.
Risk-Weighted Releases	Toxic chemicals weighted by their relative toxicity.	A more realistic depiction of health and environmental effects than unweighted releases.	Toxicity data are frequently highly uncertain; risk-weighted approach has not been generally accepted by key customers—EPA, environmental groups.
Waste per Unit of Production	Percentage of production lost as waste; generally measured by weight.	A very broadly applicable measure that incorporates efficiency in use of resources as well as containinant releases to the environment.	No priority established in terms of type of wastes; absent other measures, creates an incentive to focus on high-volume, low-toxicity wastes.

(table continues)

TABLE 1 Continued

Measure	What It Measures	Advantages	Disadvantages
Energy Use	Total energy use by all aspects of corporate operations; can be expressed also as carbon dioxide releases.	A comprehensive measure that focuses attention on efficiency in use of a key resource; anticipates possible global warming concerns; readily communicated to customer.	Energy efficiency is important, but not the only basis on which to evaluate environmental performance; other measures also needed.
Solid Waste Generation	Total solid waste going to landfills or other disposal facilities.	An important measure in the public mind because of publicity surrounding landfill capacity shortage; often reflects efficiency in resource use.	A very narrow measure of environmental performance; often misinterpreted as the most important criterion to judge performance.
Product Life Cycle	The total impact of a product on the environment from raw materials sourcing through production use and ultimate disposal.	The most comprehensive measure of product level impact; a meaningful goal to strive for in resource use efficiency and pollution prevention.	Extremely complex to implement; methodologies are not commonly accepted; claims based on product life cycle analysis are frequently treated with skepticism; difficult to apply at a corporate or unit level.

[a]SARA = Superfund Amendments and Reauthorization Act of 1986. SOURCE: Wells et al., 1993.

functions. The term should be reserved for systematic and objective evaluations that are carried out by experts who are independent of the function or location being audited. Corporate auditing, as conducted by Ciba, is a strategic management tool; it helps to ensure compliance with current legal and regulatory requirements to minimixe future risks and liabilities through a proactive approach that focuses on anticipating future requirements. Also, Ciba's approach to auditing helps to increase operating efficiency, effectiveness, and quality because it not only addresses management and control systems, but also technical, organization, and personnel issues. In summary, auditing does not simply provide a picture of a location's compliance status, it identifies weaknesses and vulnerabilities regarding continued compliance, either with today's or anticipated standards.

For any large manufacturing company, it is neither possible nor appropriate to conduct meaningful annual audits of manufacturing facilities, even the major ones. A number of audit findings may require significant effort by the facility to resolve, and it is appropriate to provide at least 2 years between audits to allow progress to be made. Also, compliance is the line responsibility of each facility, and conducting audits too frequently would tend to shift accountability for compliance from the facility to the auditors.

In addition to the information from audits, Ciba senior management needed an annual, worldwide survey to provide meaningful information on safety, energy consumption, and environmental performance. This information was needed to help set annual and periodic priorities for initiatives to improve worldwide performance in these areas. Therefore, in 1990 Ciba introduced annual reports on safety, energy, and environmental performance (commonly known as SEEP reports) to obtain accountability of safety, energy conservation, and environmental protection performance; determine performance criteria for sites; serve as a management tool; and provide information for communicating corporate performance.

CIBA'S WORLDWIDE ENVIRONMENTAL MEASUREMENT SYSTEM

For many years, Ciba's worldwide production facilities provided environmental reports to their site, national (group company), and worldwide corporate managements. However, these reports were not always comparable because they were based on the information needs of local management and the legal requirements of individual countries. These reports were of interest to the worldwide corporate headquarters, but because of their varying formats, it was not possible to consolidate the reported data to gain information on worldwide corporate performance.

In 1990, a corporatewide standardized reporting system was established, known as the annual SEEP report. All major production sites are required to complete the report, whereas submission by other sites is at the discretion of the head of the group company. The number of sites submitting SEEP reports rose from 64 in 1990 to 82 (from 17 countries) in 1992, covering all chemical production and major formulation works within Ciba and capturing annual information on greater than 90 percent of Ciba's worldwide emissions (Ciba-Geigy, 1993). The consolidated data from these reports form the basis of the corporate environmental report, which was issued for the first time in 1992. This document provides stakeholders with a report card on Ciba's environmental activities and accomplishments.

Information submitted in the annual SEEP reports falls into four categories: tabulated and charted data on safety, energy usage, and environmental protection; summaries of safety and environmental protection investment and operating costs; case studies of improved safety or environmental performance, and energy savings (and also examples of unsuccessful initiatives); and a report on any other matters of significance for safety, energy usage, or environmental protection. Table 2 summarizes and Figure 2 illustrates types of information requested under the SEEP program to measure environmental performance and energy consumption at a particular site.

SEEP has become an important management tool for Ciba, complementing the auditing program, training, and policy-making. It allows the company to measure safety, energy conservation, and environmental performance at the corporate as well as at the local level. As a result, priorities can be established;

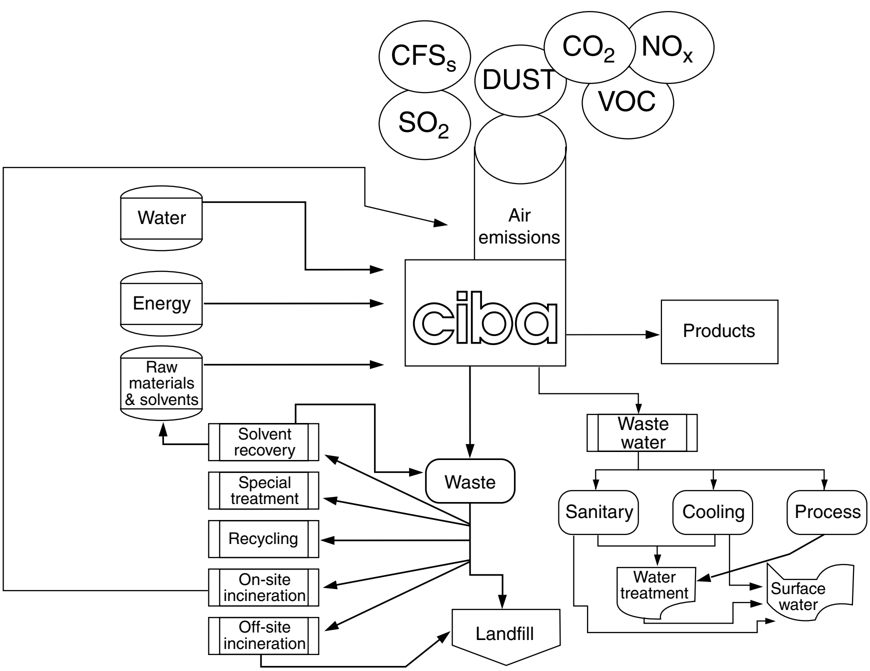

FIGURE 2 Safety, energy, and environmental protection (SEEP) information categories related to environmental and energy performance.

TABLE 2 Safety, Energy, and Environmental Protection (SEEP) Information Categories Related to Environmental and Energy Performance

General Site Data • Volume of production in tons, units, square meters, etc. • Processes discontinued for safety or environmental reasons • Water inputs and uses (process, sanitary, cooling, etc.) • Effluent discharge (type and quantity) • Noise: cases of noncompliance with legal limits • Soil, groundwater: cases of contamination • Audits or inspections by authorities, division, or group company	Water Pollution Control • Location of sampling points • Effluent volumes • Effluent quality: COD/TOC, DOX[a], and inorganic salts load regulatory values; number of excursions • Biodegradability • Other reportable substances or important wastewater variables	Air Pollution Control • Summary of emissions in tons (nonhalogenated and halogenated organics, carcinogens, organic and inorganic dusts and inorganic gases) • Emissions of individual critical substances • Chlorofluorocarbons purchased • Emissions of SO_2, NO_x, HCl, and CO_2[b] from boiler houses and incinerators
Solvent Usage (separated into halogenated and nonhalogenated categories) • Total input of solvent • Input of new solvent • Solvent recycled • Solvent sold • Solvent consumed as reagent • Waste solvent incinerated • Solvent losses	Waste Management • Type and quantity of waste • Waste treatment technique (recycling, incineration, landfill, special treatment) • Waste treatment facilities used	Energy Management • Energy sources, quantity consumed • Energy conversion, co-generation, losses • Energy consumption breakdown by category • Comments of fuel quality, sulfur content, new technology
Expenditures and Personnel for Environmental Protection • Capital investments • Operating costs • Personnel costs • Number of personnel	Cases: Environmental Successes and Failures • Prevention or reduction of water or air pollution • Avoidance or reduction of waste • Recovery, reuse, and recycling of wastes • Integrated pollution control measures • Reduction of process risks and major hazards • Progress in environmental technology • Energy conservation	Highlights: Changes, Problems, and Developments • Major problems and challenges • Legislation • Objectives • Organization and responsibilities • Technology • Monitoring and controls • Personnel awareness and training • Communications with the public and authorities • Recognition awards

[a] COD/TOC = chemical oxygen demand/total oxygen demand; DOX = dissolved organic hologen; [b] SO_2 = sulfur dioxide; NO_x = nitrogen oxide; HCl, hydrochloric acid; CO_2 = carbon dioxide.

site-specific goals can be set; specific actions can be planned, approved, and implemented; and progress can be measured.

Ciba believes that site-specific goals are more effective in achieving results than are companywide, across-the-board targets that apply to all facilities. With this approach, priorities can be set according to the highest environmental needs or to maximize the environmental return from a given investment level. For instance, it would make little sense for Ciba to establish an internal company goal of an across-the-board 10-percent volatile organic compounds (VOC) emission reduction at all sites, when three manufacturing facilities account for about half of the corporation's worldwide emissions.

Each year, the quality of SEEP data inputs has improved. When sites first started reporting in 1990, the quality of the data was not always reliable, and many of the numbers reported represented estimates rather than measured values; increasingly, the reported values are based on actual measurements.

Although completion of the SEEP report requires a significant amount of time and effort by site personnel, Ciba's experience has been that it quickly gained broad support from facilities. The SEEP information allows site managers to critically review facility environmental performance, set concrete objectives, and monitor progress over time. In addition, the information is helping sites with their local and national external reporting.

When comparing data across the corporation, remember that fluctuations occur in the number of sites reporting. This has varied as more and more small sites submit reports for the first time or as sites are acquired or sold. Hence, data are not strictly comparable from year to year but nevertheless provide a clear and valid picture of trends.

A review of the SEEP information since its inception has shown many positive results and some that are disappointing (Ciba-Geigy, Ltd., 1993):

- Between 1990 and 1992, Ciba's overall energy use increased by about 8 percent. The energy requirement was met by purchasing electricity from public utilities and primary fuels such as natural gas, oil, and coal to produce heat. These sources of energy were used directly in the buildings and processes, converted to steam for process heat, or converted to electricity in Ciba's own generators. Increased requirments for pollution control equipment and automation of processes and operations resulted in increased electricity usage of about 9 percent.
- Between 1990 and 1992, Ciba's worldwide facilities continuously reduced overall emissions of sulfur dioxide by about 43 percent. These reductions were achieved by using more natural gas, which is sulfur free; by changing from heavy to light oil, which contains less sulfur; and by increasing the incineration of wastes in units with flue-gas cleaning to remove sulfur dioxide.
- Between 1990 and 1992, Ciba's worldwide facilities reduced nitrogen

oxide emissions by about 7 percent through complex technical measures such as catalytic conversion or using "low–nitrogen oxide" burners. The process of replacing burners is ongoing.

- Ciba's worldwide carbon dioxide emissions increased from 1990 to 1992 by about 8 percent, mainly due to increased on-site incineration of wastes to produce energy. The carbon dioxide emissions resulting from incineration of wastes in third-party facilities in the past were not counted as emissions from Ciba.
- As a result of aggressive water conservation measures, Ciba has significantly reduced water use. Between 1991 and 1992, water usage decreased by about 6 percent. Much of this reduction was achieved by installing recirculating systems, which have the disadvantage of requiring additional energy for pumps and fans.
- Like most of the chemical industry, Ciba's production processes frequently require large quantities of solvent. In most processes, the solvent does not react but acts as a medium to facilitate the chemical reaction of other constituents. At the end of the process, the solvent needs to be removed and recovered or disposed of. In 1992, SEEP consolidated solvent information indicated that more than 95 percent of Ciba's worldwide solvent requirements were met through recycling. Also, between 1991 and 1992, Ciba's emissions of organic vapors to the atmosphere from production operations decreased by 11 percent.

Another measure of performance in solvent usage is the amount of halogenated solvent used. Halogenated solvents are viewed as important because of their environmental persistence and potential to bioaccumulate. As a result, Ciba places high priority on replacing them with other solvents. In 1992, 78 percent of the solvent used in production was nonhalogenated. Also, between 1991 and 1992, Ciba's emissions of halogenated organic vapors to the atmosphere from production operations decreased by about 10 percent.

One of the most important aspects of an effective environmental measurement system is the collection of data that can be meaningfully interpretated. Figure 3 is an example of an emission statement prepared for a major Ciba group company from the 1990 and 1991 SEEP data. It provides a good representation of all discharges to the air and water and the amounts of waste being added to landfills or destroyed (Rothweiler, 1994). This is an example of an effective management tool for evaluating accomplishments and prioritizing additional areas for improvement. For example, this figure shows that significant reductions in sulfur dioxide and nitrogen oxides emissions to the atmosphere have been made through the use of low-sulfur fuels and improved energy management technology. It is also clear that organic emissions need to be reduced, although substantial progress has been made in substituting nonhalogenated for halogenated organic compounds.

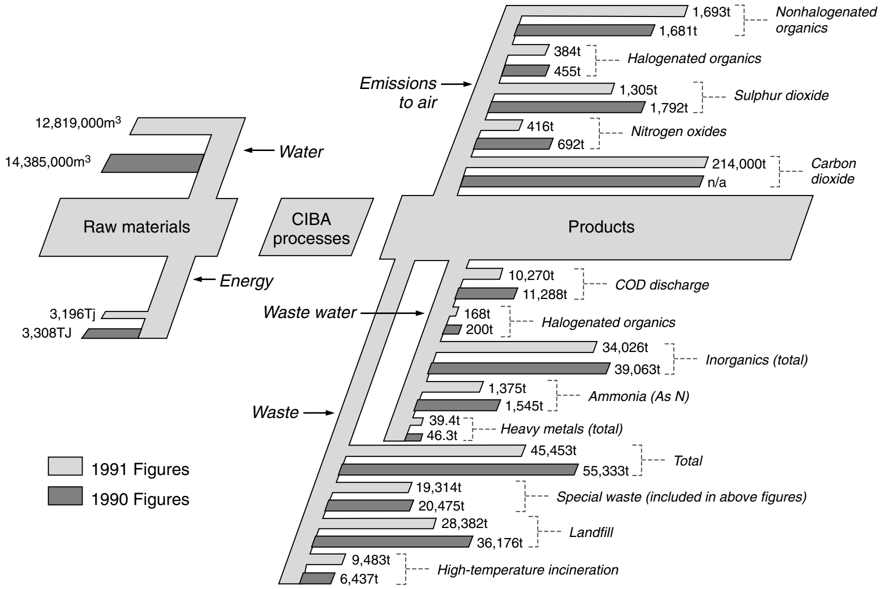

FIGURE 3 SEEP data from a Ciba company (example). t = ton; m^3 = cubic meter; TJ = tera joules.

Analysis of the SEEP data in this way provides a picture of environmental achievements from a broad operational perspective and aids in setting further goals and performance standards. However, although a graphic such as Figure 3 is effective in summarizing accomplishments across the company, it is really analysis of trends in specific site data from year to year (either by using an analysis similar to that illustrated in Figure 3 or another method) that allows targeting of specific areas for improvement.

As mentioned previously, data associated with environmental performance measurement systems can be quite voluminous, especially for large, multinational corporations. Hence, in 1993, after 3 years of experience with implementing SEEP, Ciba automated and computerized the process. Also, Ciba recently retained an independent firm to assess the SEEP program. The objectives of this independent assessment were to critically review and assess the process for collecting and analyzing the SEEP data from group companies and provide a validation assessment of the 1993 SEEP data for publication in the annual corporate environmental report.

Four years of experience with SEEP and the recent independent assessment reveal an important additional complexity for interpreting and using SEEP information as a management tool: Different measurements are required to assess environmental performance at different levels of facility operation. For example, measurement of wastewater releases from a production area to either on-site or off-site treatment provides a measure of pollution-prevention performance. However, measurement of releases to the environment after treatment only provides information on the end-of-pipe result, without regard to the progress of production processes toward preventing pollution.

CIBA'S U.S. TEXTILE PRODUCTS CUSTOMER SATISFACTION SYSTEM

Ciba's U.S. Textile Products Division (Ciba-TPD) collects customer satisfaction data monthly. To ensure objective and valid data, the surveys are conducted by an independent, third-party marketing firm. The survey consists of three parts: relative-importance rankings of the attributes being measured, numerical rating of attributes on a scale of 1 to 10, and open-ended questions to solicit information on perceived strengths, weaknesses, and future areas for improvement.

The raw data are provided to Ciba-TPD and are managed through a confidential database. Segmented information is routinely extracted from the data according to business segment, account size and activity level, the type of customer contact (production, technical, administrative, or executive), and other variables associated with the customer (such as region, sales volume, product mix, and salesperson).

Customer contacts are made across all areas of business, and the information collected addresses in excess of 80 percent of total sales as well as priority potential accounts. The customer survey solicits feedback in 14 specific areas: overall product quality, product performance, delivery service, laboratory service, field service, follow-up on requests and messages, routine customer service, special-handling customer service, organization and communication, value, price, packaging, environmental assistance, and environmental responsiveness. General information is also solicited: What are Ciba's strengths? What are Ciba's weaknesses? What will it take for Ciba to become or to stay the preferred supplier in the future?

Specific feedback sought in the environmental areas includes:

- Environmental assistance—How helpful is Ciba with assistance on product application (dyeing methods), product characteristics (material systems data sheets, ecology-toxicology data), environmental communication, environmental services?
- Environmental responsiveness—How responsive is Ciba in assisting in waste minimization, regulatory compliance, product stewardship, and environmental marketing efforts?
- Packaging—How well does Ciba's packaging meet the customer's requirements, and how does its durability, ease of use, and ease of recycling rate?

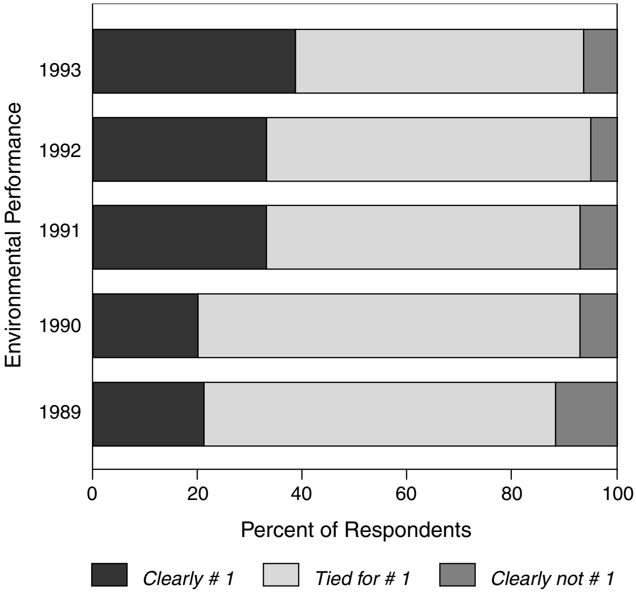

FIGURE 4 Environmental performance (Ciba-Textile Products Division vs. best competitor).

Figure 4 provides summary measurement data for the environmental assistance and responsiveness categories for the past 5 years. These results are measured relative to Ciba's best competitor. The overall environmental performance ratings by our customers for 1989–1990 indicate that a little more than 20 percent of Ciba's customers perceived the company to be clearly #1, 10 percent perceived Ciba to be clearly not #1, and the balance (slightly fewer than 70 percent) perceived Ciba to be tied for #1. During late 1990, Ciba-TPD began concerted efforts to improve their overall environmental performance, as perceived by their customers, and in 1993 40 percent of Ciba customers perceived Ciba to be clearly #1, or nearly double the 1989–1990 average results; fewer than 10 percent perceived Ciba to be, clearly not #1, a modest decrease from the 1989–1990 average results; and 50 percent perceived Ciba to be tied for #1.

These environmental performance numbers indicate that by 1993, more than 90 percent of the company's customers perceived Ciba-TPD to be #1 or tied for #1 with the company's best competitor, and major gains were made in comparison to best competitor since 1989-1990, as evidenced by the doubling of the company's clearly #1 ratings.

As described above, solicited feedback on packaging includes a number of attribute measures, one of which is environmental (i.e., ease of recycling). Figure 5 provides summary measurement data for packaging overall for the past 3 years. Although Ciba-TPD has invested significantly in improving its packaging during

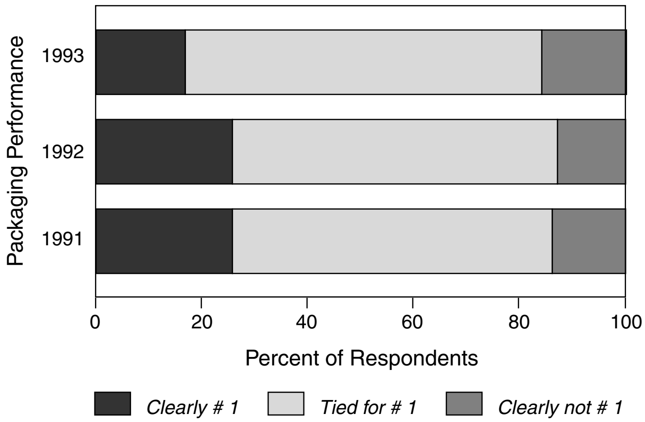

FIGURE 5 Packaging performance (Ciba-Textile Products Division vs. best competitor).

this time, the data indicate that the company's overall position of being clearly #1 or tied for #1 has remained relatively stable (85 percent) whereas the company's position for clearly #1 appears to have slipped somewhat in 1993.

This information indicates a highly competitive marketplace, with significant attention being paid to this attribute by the company's competitors. In response, Ciba-TPD has established aggressive goals and implementated plans to further improve packaging. One example of the packaging goals pertains to the percentage of the packaging deemed to be environmentally friendly.[3] Figure 6 illustrates the past 3 years of performance in this area and shows the goals for 1994 and 1995. In summary, between 1991 and 1995, Ciba-TPD planned to go from 10 percent to 98 percent environmentally friendly packaging. By the end of 1993, a sixfold increase to 60 percent environmentally friendly packaging had already been achieved.

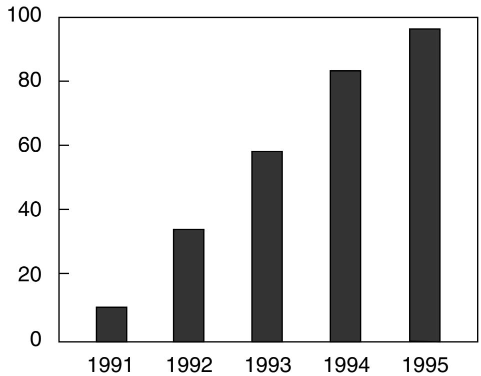

FIGURE 6 Environmentally friendly packaging, by year (Ciba-Textile Products Division).

SUMMARY

Since the first Earth Day in the early 1970s, the impact of businesses' environmental performance has been growing; by the 1990s, it had become a major driving force in determining long-term success. Positive environmental performance in industry requires leadership from the top and commitment throughout the company as well as allocation of significant human and financial resources. Because of limited resources, companies must be able to identify and select issues on which to act where their investments will yield the most cost-effective benefit. Such action can turn improving environmental performance from a perceived liability into a real competitive advantage.

Identification and prioritization of environmental issues requires effective measurement of environmental performance. Periodic compliance auditing should not be confused with environmental measurements. Generally, auditing is conducted by independent experts every several years, whereas environmental measurement data are self-reported by each facility at least annually. Implementation of an environmental measurements program is a long-term commitment. In concert with their goal to help identify and prioritize issues for action, such programs are intended to foster continuous improvement, which requires measurements to evaluate the results.

Development and use of environmental measurement systems is still in its infancy, and the systems continue to evolve rapidly. Because environmental issues are complex and often interrelated, effective environmental measurement systems can become quite complex, and initial implementation can appear to be an overwhelming task. However, initial implementation of a rather straightforward system, with a recognition that continuous upgrading and improvements will be necessary, is a manageable approach that will begin the process of continuous improvement of environmental performance.

NOTES

1. Environmental performance can be defined as an organization's achievements in managing the relation between the full range of its activities and their environmental risks and effects (ISO/TC 207 Environmental Management Subcommittee #4, 1994).
2. Environmental performance evaluation can be defined as a process to measure, analyze, assess, and describe an organization's environmental performance against agreed criteria for appropriate management purposes (ISO/TC 207 Environmental Management Subcommittee #4, 1994).
3. Ciba-TPD defines environmentally friendly packaging as containers (e.g., returnable drums or totes and bulk shipments) that are reused, not disposed of. Every pound of product delivered to customers is tracked on a monthly basis according to this definition.

REFERENCES

Ciba-Geigy. 1993. Corporate Environmental Report 1992. Basle, Switzerland: Ciba-Geigy.

FitzGerald, C. 1993. Selecting measures for corporate environmental quality: Examples from TQEM companies. Pp. 15–23 in Measuring Environmental Performance. New York: Executive Enterprises Publications Co.

ISO/TC 207 Environmental Management Subcommittee #4. 1994. Environmental Performance Evaluation Framework Document on Definitions, Principles and Methodology. Final draft.

Rothweiler, W. 1994. Reviewing and monitoring environmental performance. Environmental Management Handbook, B. Taylor, C. Hutchinson, S. Pollack, and R. Tapper (eds.), London: Pitman Publishing.

Wells, R.P., M.N Hochman, S.D. Hochman, and P.A. O'Connell. 1993. Measuring environmental success. Pp. 1–13 in Measuring Environmental Performance. New York: Executive Enterprises Publications Co.

The Industrial Green Game. 1997. Pp. 148–153.
Washington, DC: National Academy Press.

Hydro Aluminum's Experience with Industrial Ecology

ROLF MARSTRANDER

The recent emergence of broad-based ideas such as life cycle analyses, clean technology, environmentally conscious manufacturing, and design for environment indicate a shift from a linear, process-oriented focus to a more systems-oriented view that is characterized by industrial ecology. The industrial ecosystem at Kalundborg illustrates an integrated system of industrial activities consisting of an electric power plant, an oil refinery, a biotechnology plant, a plasterboard factory, sulfuric acid producers, cement producers, local agriculture and horticulture, and district heating (Grann, this volume, pp. 117–123). This cluster of industries minimizes energy and studies waste losses from the system.

Other cases from companies around the world show how industry can contribute to sustainable development (Willums and Ulrich, 1994). Beginning with the critical need to formulate goals related to the areas identified for improvement, the case studies demonstrate the organizational dedication and the technical ability required to improve processes and use waste. They also show the value of cooperative alliances with customers, suppliers, and the surrounding community for improving environmental performance. Dow Chemical's Waste Reduction Always Pays program, 3M's legendary Pollution Prevention Pays, and Du Pont's targets to reduce pollution are examples of these practices. These companies have publicly committed themselves to reduce waste and have translated their commitments into intercompany programs for improvement.

The pollution prevention activities of companies fit the industrial ecology context. Industrial ecology has been described as a new approach to the industrial design of products and processes and the implementation of sustainable manufacturing strategies. It is a concept in which an industrial system is viewed not in isolation from but in concert with its surrounding systems. Industrial ecology seeks to optimize the cycle of virgin material to finished material, including components, products, and waste products (Jelinski et al., 1992).

The concept of industrial ecology, therefore, extends beyond the typical flow of materials in a process industry (such as an oil refinery) into the manufacturing industry, where separate companies with different processes, movements of material, and operations contribute to a final product. Manufacturing is a complex system with an almost unlimited number of different but related variables that can influence sustainability. The complexity is best illustrated by the fact that, depending on boundary conditions, a full life cycle analysis of a beer can include as many as 600,000 data items (Pomper, 1992).

Paradoxically, a systems-oriented and sustainable approach to the design of manufacturing and products means that the complexity needs to be simplified. Simplification can be achieved by limiting the number of variables to be tracked through a system or by organizing them so that consequences from different design strategies can be evaluated, such as in Volvo's Strategies in Product Design (Horkeby, this volume).

ONE COMPANY'S EXPERIENCE WITH INDUSTRIAL ECOLOGY

Hydro Aluminum, a fully owned subsidiary of Norsk Hydro, manufactures two classes of product: semifabricated products (such as aluminum sheets) and end products (such as aluminum cans). The company has approached industrial ecology by focusing on understanding its products.

Aluminum offers several benefits in its many applications in the economy. It has a positive strength-weight ratio, is noncorrosive, is a good conductor of heat, and is excellent for food and beverage packaging. In terms of its environmental impact, energy consumption is high for initial production and low for recycling. Typically, 35 kilowatt-hours (kwh) are required for processes leading to primary aluminum and 1.7 kwh are required for recycling. Most of the emissions arising from the extraction, production, use, and recycling of aluminum are from primary production.

These characteristics necessitate a proactive approach to all environmental, health, and safety (EHS) matters and the need to highlight the advantages of aluminum from a life cycle perspective. In 1991, Hydro Aluminum began its program of ecological responsibility, which is based on an understanding of industrial ecology as a systems-oriented approach to EHS management. Under this program, the process-oriented EHS functions are a part—but not all of—industrial ecology.

Two different dimensions of industrial ecology are important to the firm. One is related to information and education of the company's employees and the general public. The other is related to product, system, and process development defined by market needs and economic and technical feasibility.

Hydro Aluminum initiated several steps to increase awareness about the industrial ecology of the business: Life cycle data relevant for products and processes were determined; a better understanding of what industrial ecology will mean for aluminum in three sectors—the auto market, the building market, and the can market—was developed; and the company published *Aluminum and Ecology*, a detailed brochure, and put industrial ecology on the agenda in its internal training programs.

These efforts focused on life cycle considerations, strategic market needs, and training or information needs. They revealed the following:

- Industrial ecology provides a good basis for communicating with major customers. Smaller customers tend not to identify the challenge or appreciate the idea of industrial ecology as much as larger companies, such as car makers that operate in more clearly identified markets. Smaller companies, such as builders in loosely defined markets, tend to ask what is in it for them and do not see the broader market forces influencing their future.
- Detailed business-related environmental data need to be presented in a usable, easily understandable way.
- A detailed and open record related to ecology and the environment results in positive media coverage and public response.
- To be operational in the business context, the application of industrial ecology has to be simplified.
- Environmental concerns are additional factors to consider in technological innovation. The link between the end use of aluminum in the final product (the use of the product by the consumer and its final disposal and recycle) places new and strong demands on the design of products and on cooperation among the different participants in the life cycle of the material.
- The integration of environmental considerations within a company begins with small specific steps.
- Hydro Aluminum will continue its two-pronged approach of providing information and communicating with the market while engaging in more specific development and design activities.

INDUSTRIAL ECOLOGY AND ALUMINUM

Managing a firm from an industrial ecology perspective encompasses recycling, energy consumption, logistics and use of packaging material, and EHS concerns. These factors cover most of the challenges of developing and judging appropriate processes and strategies for optimizing the use of aluminum in light of the technological, economic, and ecological constraints. These factors are also of concern to society at large, and they pose technical and scientific challenges that requires a systems-oriented approach. The challenge to management includes economic and organizational change as well as opportunities for products and markets.

Industrial ecology also requires the consideration of the relationship between natural ecology and industrially generated emissions, discharges, and wastes. This necessitates that a firm seek answers beyond its boundaries. Hydro Aluminum is working through the Norwegian aluminum industry, in cooperation with Norwegian universities and research institutes, to carry out extensive studies of the effects and, when possible, the dose-response characteristics of emissions and discharges from its aluminum plants. This scientifically demanding task is intended to define targets for future emission and discharge standards. In effect, these studies will define research and development objectives for the company's processes and provide information on the overall life cycle of aluminum.

Hydro Aluminum also recognizes the need for life cycle data on products in the markets for each of the company's operations or divisions. Some data will be common for all downstream activities, others will be specific for a particular division in a particular market. Such data are needed to help the company develop its strategies and to provide specific information about environmental communications material. In cooperation with the European oil industry, Hydro Aluminum is working to establish common life cycle data for typical products.

FROM LEARNING TO DOING

The general findings from the initial projects undertaken at Hydro Aluminum illustrated the complexity of the life cycle perspective. The complexity is revealed in product- and market-specific projects, where the company must identify challenges and needed improvements, consider building new business relationships, and consider expanding cooperation within existing relationships. Taking environmental considerations into account in making business decisions has resulted in improvements in several areas.

Process and In-House Activities

In addition to the ongoing EHS efforts, the focus on process has led to energy-efficiency improvements. The obvious means of improving energy use in processes is to adopt technologies that provide that advantage. Hydro Aluminum has initiated energy-efficiency improvement programs in all its Norwegian plants and is collecting life cycle data to link total energy consumption to products from the various plants. The life cycle perspective also suggests that the company should recover as much aluminum as possible from downstream recycling activities; processing aluminum from recycled aluminum products requires much less energy than does processing aluminum from virgin sources.

Customer and Market Activities

Projects related to customers and markets are aimed at building links to customers to address more effectively the life cycle challenges facing the company. In addition, Hydro Aluminum has gained a much better understanding of logistical challenges and is finding ways to improve distribution and recovery logistics by working with selected customers.

Hydro Aluminum has focused on logistics because material used in packaging contributes to waste, and the public is concerned about overcrowded and environmentally unfriendly transportation systems. Energy data related to the logistics of distributing and recycling aluminum products are needed. In addition to affecting energy use and environmental impact, improved logistics can help realize cost and capital savings. By selecting a few projects and working with customers to analyze the transportation logistics involved, opportunities to improve the use of packaging material and patterns of transport and recycling have emerged.

Cooperation with customers has provided the company with a better understanding of the metallurgy in some markets that favor closed-loop recycling and has highlighted the importance of using systematic approaches to sharing data with large customers and helping more resource-limited customers. In the building market, which consists of smaller customers and fewer social and environmental pressure to recycle, cooperative links are weak. As a big company dealing with many smaller customers, Hydro Aluminum increasingly finds it has to take the lead in defining research and development needs and gathering data for life cycle studies.

THE IMPORTANCE OF INFORMATION AND EDUCATION

The most significant lesson Hydro Aluminum has learned from its industrial ecology experiment is the need to inform and educate. In the mid-1980s, Hydro Aluminum and several other big companies were under attack by environmental groups. Norsk Hydro, Hydro Aluminum's parent company with a turnover of roughly 60 billion NOK (about one-tenth of Norway's GNP of about 650 million NOK), was considered "a good enemy." It was operating its plants within government regulations but could do better by 1990s standards. The 1980s experience led to a change in information strategy.

Today, the company's policy is to be completely open about EHS matters. The change in policy results from a recognition that environmental groups represent society at large, and the company's employees are also members of society. Because the information the company provides to regulators is passed on to society, it seems prudent to directly communicate with the public. Well-informed employees are a company's best ambassadors, which means that a company needs to inform and educate its own employees. Environmental matters involve complex scientific facts, uncertainties, and intangibles. An incomplete representation of the facts leads to a loss of public confidence, so there is a need to provide credible information to the public. By improving communications with employees and the public, Hydro Aluminum, like many companies in Europe, has made significant gains in improving relations with a range of stakeholders.

To defend aluminum against biased life cycle analyses, Hydro Aluminum has established programs to educate its employees and the public about aluminum's advantages and disadvantages, its applications, and its environmental effects. This outreach effort also provides information about the company's industrial ecology approach to environmental management. The challenge posed by this education effort is to maintain an openness without leaving a negative image of aluminum.

Industrial ecology adds several dimensions that transcend the traditional scope of environmental communication. Industrial ecology focuses on a totality and an understanding that link environmental problems and consumption to production. Information, therefore, has to link consumers and producers in understanding their roles in implementing options to solve problems. This makes the concept of industrial ecology difficult to understand fully and requires even more information and ways to integrate that information in decision making. The focus of engineering and management training has to move away from single processes toward consideration of whole systems.

CONCLUSION

Thinking of industrial ecology as a system helps identify areas for improvement, builds links to customers, and identifies potentially competitive markets. Market research in specific major markets, the continued growth in government regulations, and the general response to Hydro Aluminum's environmental reports suggest that ecology is of increasing importance in the marketplace. Technological development is needed to improve processes and products. Long-term, system-based approaches will have to be translated into simple tools for analysis of product, processes, and operations. Stronger links between industry and academia are needed to establish theory and methods that move society toward greater environmental sustainability.

REFERENCES

Jelinski, L. W., T. E. Graedel, R. A. Landise, D. W. McCall, and C. K. N. Patel. 1992. Industrial ecology: concepts and approaches. Proceedings of the National Academy of Sciences of the USA 89:793–797.

Pomper, S. D. 1994. Life cycle assessment of aluminum. Paper presented at a workshop on product stewardship. Massachusetts Institute of Technology. Boston. March.

Willums, J., and G. Ulrich. 1994. From ideas to action. Pp. 49–79 in Business and Sustainable Development. Paris: International Chamber of Commerce.

The Industrial Green Game. 1997. Pp. 154–164.
Washington, DC: National Academy Press.

Europipe Development Project: Managing a Pipeline Project in a Complex and Sensitive Environment

HENNING GRANN

This paper describes steps taken by Den norske stats oljeselskap a.s. (Statoil), as operator of a group of companies, to build a 640-kilometer (km) pipeline from the Norwegian North Sea through an ecologically sensitive area to a new gas terminal in Emden, Germany.

The offshore pipeline is being landed in the Wadden Sea National Park of Lower Saxony, a unique wetland of extreme environmental importance and sensitivity. Final approval for the landfall part of the project was given in late 1993 by German authorities after detailed discussions and a thorough evaluation of several pipeline routes, construction alternatives, and comprehensive environmental impact assessments.

To ensure a high level of environmental performance and strict adherence to all regulations, permits, and requirements, Statoil prepared a detailed environmental protection plan for the pipeline project. A particularly important feature of this plan is the inclusion of a set of environmental documents in which the contractors state their commitment to environmental protection by identifying environmentally critical operations, prescribing appropriate environmental measures, and giving detailed work instructions for proper job execution, control, and verification.

BACKGROUND

The consumption of natural gas in Western Europe has gradually increased since the 1970s, and this trend is expected to continue well beyond the turn of the century. The increasing use of natural gas is a result of European governments' strategy to improve the security and flexibility of energy supplies. Moreover, substitution of natural gas for coal and oil will contribute to environmental improvement and will be an important instrument in attempts by governments to realize their objectives of stabilizing carbon dioxide emissions, which are viewed as probable contributors to the greenhouse effect and global warming.

In the early 1970s, a consortium of continental companies purchased large volumes of gas from the Norwegian Ekofisk offshore fields with the objective of securing a long-term supply of gas to Western Europe. The resulting Statpipe/ Norpipe gas pipeline from the Ekofisk Fields to Emden was operational in 1977. After the Troll gas sales agreement in 1986, a decision was made to develop the Troll and Sleipner gas fields; the Zeepipe pipeline was landed in Zeebrügge in Belgium and commissioned in 1993. The Troll and Sleipner gas fields in the Norwegian North Sea are interconnected with Ekofisk and other fields. Figure 1

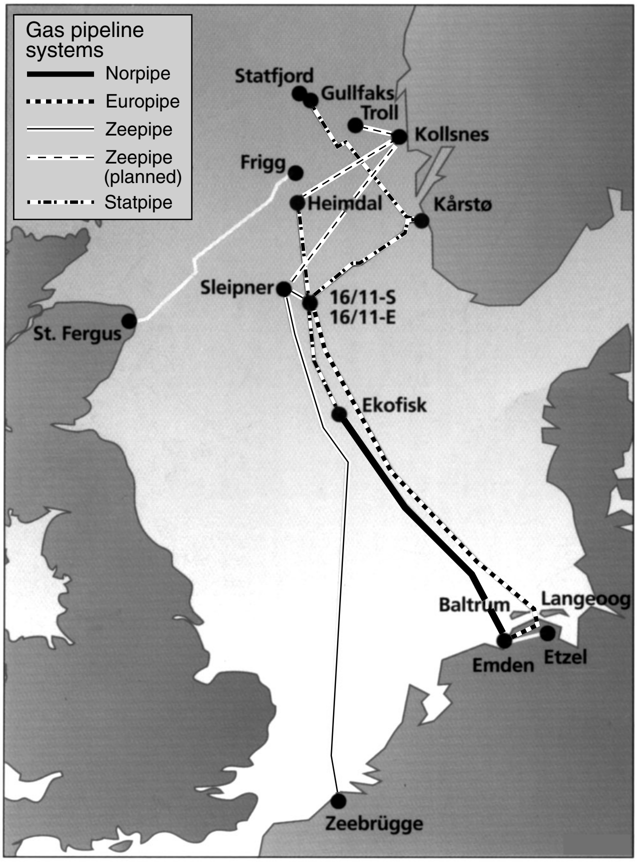

FIGURE 1 Pipelines link Norway's offshore gas fields with consumers in continental Europe and the United Kingdom. SOURCE: Statoil, 1993.

shows these pipelines, the newer Europipe line, and their connections from Norway's off-shore gas fields to continental Europe and the United Kingdom.

During 1988, it became apparent that transportation capacity to the European continent would have to be increased to meet mid-1990s demands. The increased demand would result from higher sales volumes under existing agreements and new additional gas sales agreements signed by German and Dutch buyers. To meet the increased gas supply obligations, several supply alternatives were examined, including updating the existing pipeline systems to higher operating pressures; changing the gas delivery points for certain requirements; building an offshore pipeline to Denmark and an onshore pipeline through Denmark and Germany to Emden; and building an offshore pipeline to the Netherlands or to Germany with a connecting onshore pipeline to Emden. In fall 1990, a decision was made to develop the documentation required to secure permission to land a new Europipe offshore pipeline in Germany and connect it with an onshore pipeline to Emden.

PROJECT PLANNING AND APPROVAL

The 1990 decision resulted from contacts initially made in 1985 between Statoil and the German authorities on the first feasibility study of landing an offshore pipeline in Germany. This study was followed by a preliminary evaluation of 10 alternative routes along the German North Sea coast. In the meantime, in 1986, the Wadden Sea National Park of Lower Saxony was formally established to protect a major part of the German coastline.

In accordance with the regional planning procedure, in early 1991, Statoil submitted its first formal request for permission to plan a pipeline landfall via the island of Norderney, one of the islands of the Wadden Sea and a part of the national park. The alternative originally favored by the authorities was a pipeline crossing Norderney and the Wadden Sea, but this time the political situation in Lower Saxony had changed. There was greater cooperation between the Social Democrats and the Green Party, and environmental issues gained importance as environmental organizations increased their influence in the decision process. This situation increased the difficulty of developing a pipeline project that would satisfy the interests of the general public and the authorities. Consequently, numerous alternative pipeline routes, technical solutions, and associated environmental impact assessments were developed for review by the authorities.

In November 1992, Statoil received permission to plan a Europipe landing by crossing the national park through the Accumer Ei tidal channel and a subsurface tunnel under the tidal flats. After further optimizations of this alternative, final construction permission was given on October 27, 1993.

THE TECHNICAL COMPLEXITY OF THE EUROPIPE PROJECT

Several facilities were required to bring the gas from the Norwegian North Sea to the contractual delivery point in Emden. Offshore, a new riser platform bridge (16/11-E in Figure 1) in the Norwegian North Sea connects Europipe to the Zeepipe and Statpipe/Norpipe system. It carries pressure-monitoring equipment and is intended to be a safety valve on the pipeline system. If also has equipment to launch and retrieve inspection probes and "pigs" used to clean the line.

The 640-km offshore pipeline from the riser to within 5 km of Germany's coastline is made up of 12-meter (m) lengths of steel pipe measuring about 1 m in diameter. Each section of pipe is welded and checked on the laybarge before being slid onto the seabed. The seabed is inspected by sonar and remotely operated vehicles before pipe is laid.

Closer to the coast, the large laybarge used in the open sea is replaced by smaller vessels better able to navigate narrow channels and shallow water. The pipeline is laid across a large sand bank and up the tidal channel between Baltrum and Langeoog Island; it continues until the coastal wetlands of the Wadden Sea are reached at the Accumersieler Balje (Figure 2), where a 12-m-diameter, 20-m-high cylindrical tie-in chamber is used to recover the tunnel boring machine and to install the pipeline tie-in connections (Figure 3). In the territorial waters up to the tunnel tie-in chamber, the pipeline is permanently buried in the sea bed. For this purpose, a trench is dredged in the seabed into which the pipeline will be laid by a special laybarge moored, as needed, to mooring piles. The trench is backfilled when the pipelaying is finished.

Extensive dredging (estimated 3.2 million cubic meters) is required in this very environmentally sensitive area. The great variations in water depths and tidal currents among individual route sections require the use of many different types of equipment and innovative construction methods. At the peak of the construction activities, more than 60 vessels will be operating simultaneously in the area. The varied geological conditions along the route, with different kinds of sand and clay, including peat, require special handling during tunnel excavation and trench dredging.

The sensitive Wattenmeer wetlands area of the Wadden Sea is crossed by a 2.6-km tunnel driven 7 m to 8 m under the seabed, between the tie-in chamber and dry land behind the dikes west of Dornumersiel (Figure 4). Beginning behind the coastal dikes, 3m-diameter concrete pipes are rammed behind the tunneling machine by hydraulic jacks. These pipe casings prevent the tunnel from collapsing. When completed, the tunnel is filled with water. The pipeline is floated through the tunnel as lengths of pipe are welded together on land. This land-originating pipeline is joined in the underground tie-in chamber to the section laid in from the sea. After construction is completed, the chamber is removed and the construction site behind the dykes is restored to its original use as farm land.

In early March 1994, Statoil was given permission by the German authorities

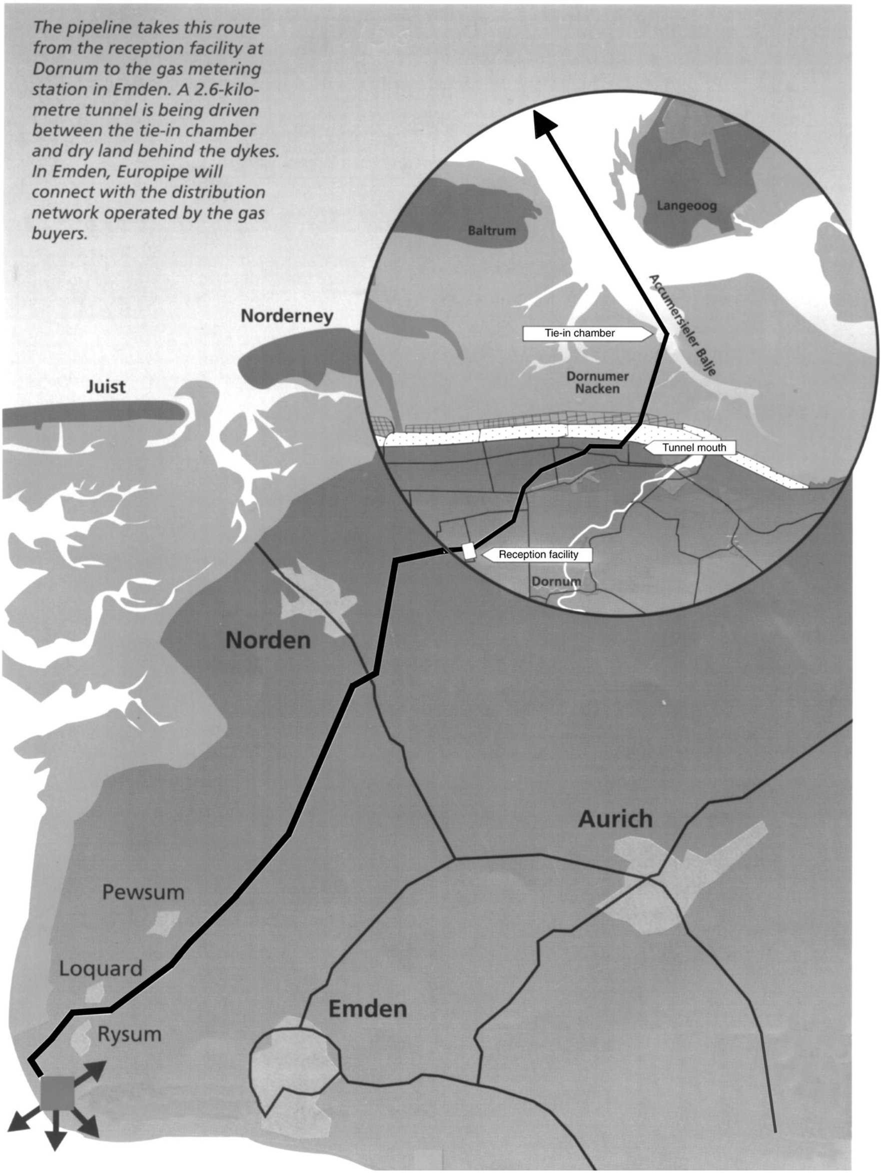

FIGURE 2 Route of pipeline on land. The pipeline goes from the reception facility at Dornum to the gas metering station in Emden. A 2.6-km tunnel is being driven between the tie-in chamber and dry land behind the dikes. In Emden, Europipe will connect with the distribution network operated by the gas buyers. SOURCE: Statoil, 1993.

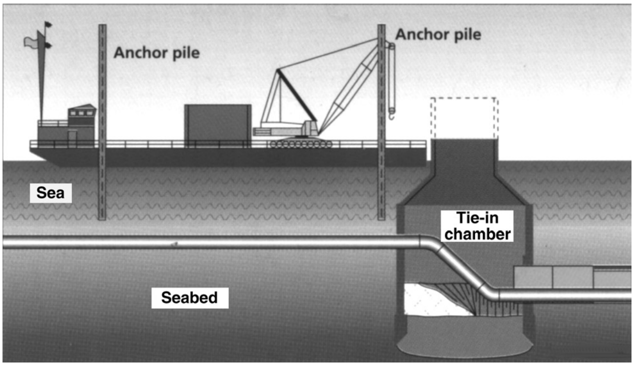

FIGURE 3 The tie-in chamber. Once the tie-in has been finished, most of the underground chamber will be removed. The rest will remain under the seabed. SOURCE: Statoil, 1993.

to lay a section of pipeline parallel with the Europipe pipeline through the tidal channel and the tunnel in anticipation of having to construct a second pipeline to meet future needs. By laying the two pipelines simultaneously through the environmentally critical area, environmental impact can be minimized.

On land, a gas-reception terminal is built close to the Europipe landfall. Norwegian gas arrives at the reception terminal under high pressure, is heated, and has its pressure adjusted. Three identical process trains are installed at the terminal. Each performs three serial functions: preliminary filtering, heating, and pressure reduction. Two of the process trains are intended for normal operations, the third is used for maintenance and other stoppages.

From the reception terminal, the gas is carried overland 50 km to Emden through a pipeline buried in a trench to a depth of at least 1 m. Several roads, railway lines, and canals are crossed. The 12-m pipe sections are welded into lengths up to 1,400 m before being lowered into the trench by a set of cranes.

SPECIAL CONSIDERATIONS OF THE WADDEN SEA

The Wadden Sea covers almost 8,000 square kilometers (km^2) and stretches from Esbjerg in Denmark in the north to Den Helder in Netherlands in the south. It is a complex environment comprising a network of tidal channels, sand bars, mud flats, and salt marches. Approximately half of the Wadden Sea lies exposed at low tide. The area represents the largest unbroken stretch of intertidal mud flats in the world. The Wadden Sea is protected from the open North Sea by a chain of about 50 islands and sand bars covering an area of about 1,000 km^2. Figure 5 shows the coastal terrain in relation to the Europipe gas line. The Wadden Sea is a unique and dynamic transition zone between the open sea and land.

The Wadden Sea ecosystem is characterized by its enormous biological pro-

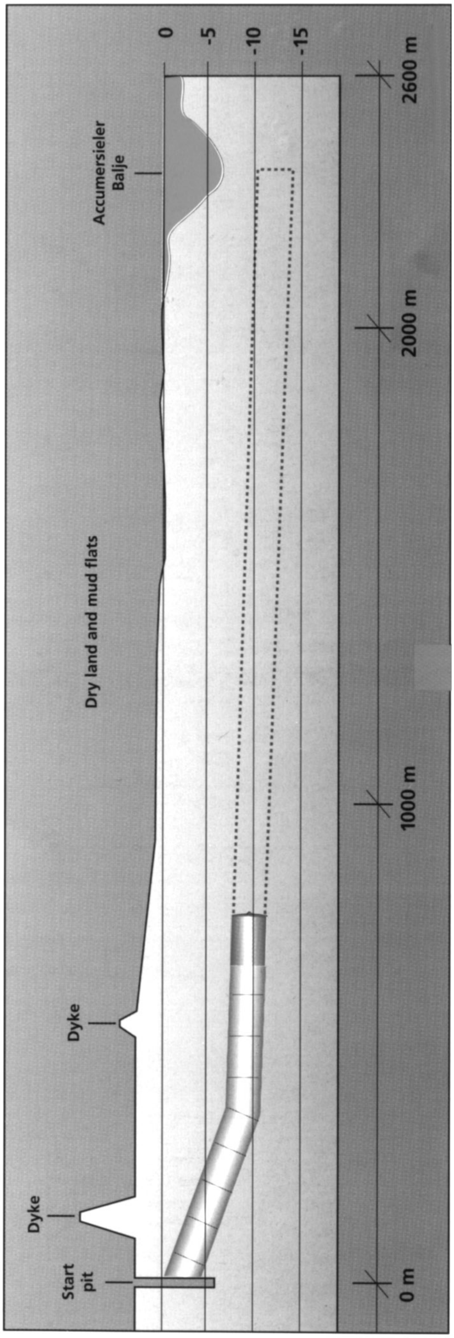

FIGURE 4 The construction of the 2.6-km tunnel under the Wattenmeer wetlands of the Wadden Sea that are exposed at low tide.
SOURCE: Statoil, 1993.

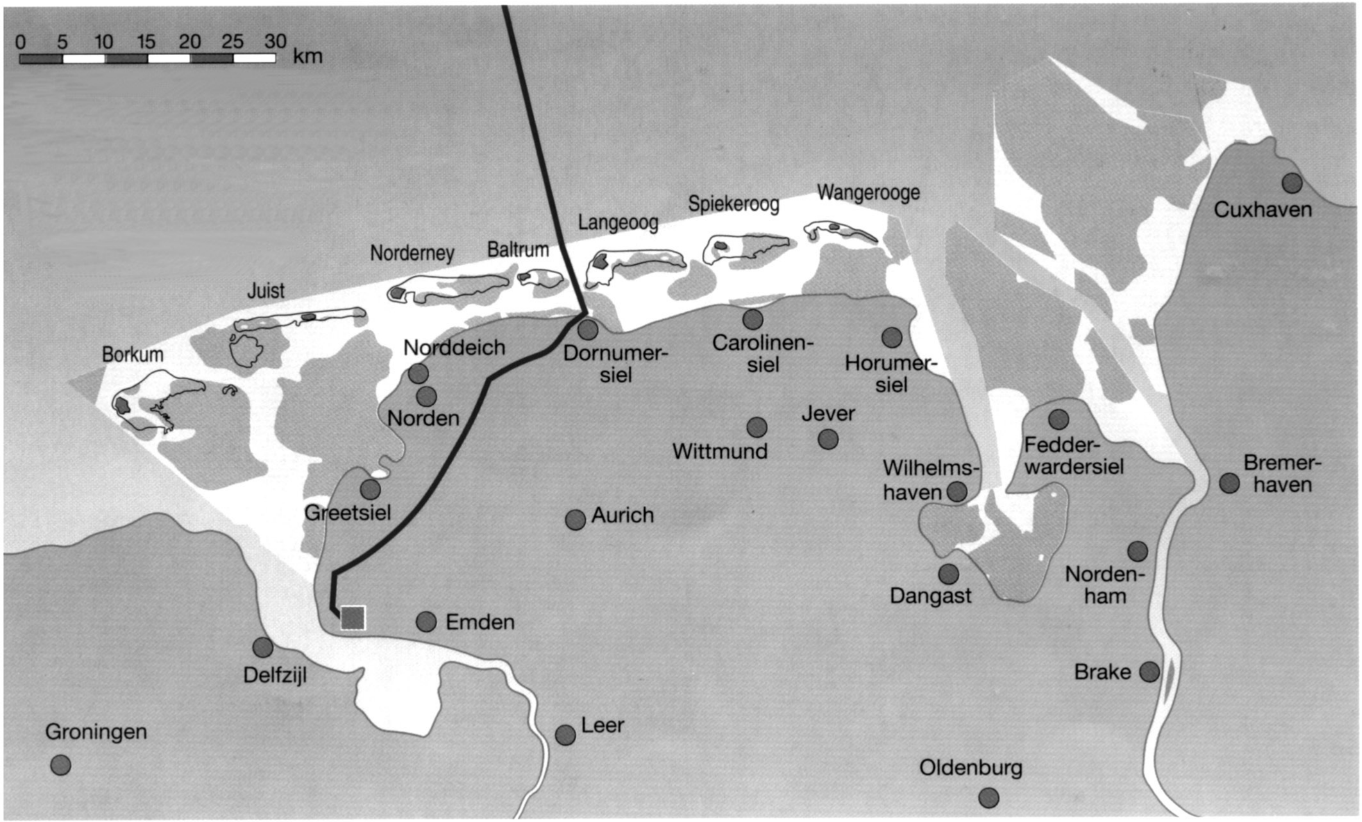

FIGURE 5 The coast traversed by the Europipe gas line. SOURCE: Statoil, 1993.

ductivity and richness on all ecological levels, from algae, invertebrates, and fish to birds and seals. The Wadden Sea is a nursery for numerous species of fish. Although the fish are hatched in the North Sea, the Wadden Sea offers shelter, space, a suitable temperature, and above all an abundance of food for the young fish. Millions of birds find an important refuge in the Wadden Sea within its extensive breeding, resting, moulting, and feeding area. The area is used by migratory birds, notably waders, ducks, and geese. Most of these birds breed in the Arctic and sub-Arctic regions of Europe and Asia and use the Wadden Sea, with its vast food supply, as a temporary stop for building the fat reserves required to successfully breed and to survive the winter.

The Wadden Sea National Park of Lower Saxony was established in 1986. It comprises some 2,100 km^2 divided into three zones on the basis of environmental sensitivity and subsequent need for protection. Stringent regulations apply, from a general policy in the Quiet Zone to less demanding rules in the Recreation Zone.

The Wadden Sea is well-known internationally for its great scientific, conservation, recreation, and commercial value. The ecosystem is considered to be one of the most important in the world, which means that many different interests are active in preserving the area for the future. The Wadden Sea National Park of Lower Saxony is recognized as a Wetland of International Importance under the Ramsar Convention, as a Special Protection Area under the European Union Bird Directive, and as a Biosphere Reserve by the United Nations Educational, Scientific, and Cultural Organization.

ENVIRONMENTAL PROTECTION PLAN

Because the new Europipe pipeline is being landed in a national park containing a unique wetland of extreme environmental importance and sensitivity, the project has been through a very detailed, resource- and time-consuming planning and approval process. The project continues to receive much attention from politicians, authorities, the press, environmental groups, and local communities. Very stringent environmental protection requirements have been set by the authorities and by Statoil management, including zero dumping and zero emissions of solid waste and liquid effluents. In addition, low emission levels of sulfur dioxide and nitrogen oxides have been specified.

To ensure a high level of environmental performance and strict adherence to all regulations, permits, and requirements, Statoil has prepared a comprehensive environmental protection plan. This plan covers the need for environmental studies, environmental impact assessments, ecological monitoring programs, communication with authorities, internal and external communications, information and training, ecological compensation measures, environmental management of construction activities, and environmental audits, verifications, and management reviews.

Ecological Monitoring Program

The Europipe construction permit approved by the German authorities requires Statoil to initiate a comprehensive ecological monitoring program for the landfall area of the national park. The objective of this program is to provide a description of the state of the total ecosystem before, during, and after the pipeline installation to identify any disturbances or changes to the ecosystem originating from the pipeline construction activities. The program will also permit evaluation of the assumptions of the environmental impact assessments for building this pipeline and will be used in planning future construction projects. The monitoring program covers sedimentology, hydrodynamics, morphology, benthic fauna and flora, fish and decapodes, and avifauna. The work is being carried out under the coordination of the national park authorities by a number of reputable German and Dutch institutes in cooperation with Statoil.

The program is well under way and may continue for several years after project completion. Because of the environmental precautionary measures taken, the final conclusions of the ecological monitoring program should show limited adverse environmental damage with few or no permanent effects.

Environmental Management of Construction Activities

Particularly important to the environmental protection plan are implementation, control, and verification of the specific environmental protection measures required to ensure minimum or no adverse environmental effects of the construction activities. Statoil has found the British Standard BS 7750, Specification for Environmental Management Systems, to be very useful in developing appropriate environmental planning documentation. With BS 7750 as a basis, the project contractors have been requested to prepare three levels of environmental documents.

- Environmental management manual. In this document, the contractor states the company's commitment to a high standard of environmental performance and describes how the company intends to carry out the environmental management. The manual addresses such things as environmental policy organization, personnel qualifications, regulations and permits, environmental impacts, environmental objectives, and audits and reviews.
- Environmental protection program. This documentation provides considerable detail based on the principles and statements outlined in the management manual. The program describes critical operations, possible adverse impacts of critical operations, protective measures, program implementation, control and verification measures, and emergency planning.
- Operational control sheets. These documents provide instructions for ex-

ecution, inspections, and control of specific environmentally critical operations. The sheets cover activity definition, responsibility and authorization, plan for work instruction, description of execution, control and verification, and deviation handling.

In addition to the contractors' own control activities, Statoil is carrying out separate environmental inspections, management reviews, and environmental audits.

CONCLUSIONS

Ecological monitoring programs will continue for several years after the pipeline is constructed to determine the extent of possible long-term effects on the environment.

In landing the pipeline in the complex and sensitive environment of the Wadden Sea National Park, it has been necessary on several occasions to use new, nontraditional, and untried technology. Completing the Europipe project successfully, particularly regarding environmental protection, remains a major challenge.

Preliminary indications are that the environmental management approach chosen by Statoil is effectively managing the complex environmental challenges of the project. BS 7750 has been very useful in creating the required contractor commitments to environmental protection and as a guide in developing appropriate environmental measures.

The environmental management experience gained will undoubtedly be a major input to the development of an environmental planning model for future Statoil construction projects.

REFERENCE

Statoil. 1993. Development and Construction of the Europipe Line. Munich, Germany: Statoil.

The Industrial Green Game. 1997. Pp. 165–181.
Washington, DC: National Academy Press.

Environmental Strategies in the Mining Industry: One Company's Experience

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"Mining" probably conjures several images. One familiar scene is of the old West, where prospectors blast the sides of mountains, tunnel through the earth, or pan at a river's edge for gold. Another is of environmental impacts of acid mine drainage from older mines that did not benefit from modern technology and management practices. The common view of mining is of environmental degradation. Few individuals outside the industry are aware of modern mining practices and associated business, environmental, and public policy issues (highlighted in Appendix A) or of how mining companies are responding to today's environmental challenges.

The extraction of ore from underground or surface mines is but one stage in a complicated and time-consuming process of producing minerals. A mine is born through exploration and mine development. This is followed by mining and beneficiation, and ends with mine closure and rehabilitation. A mining company must undertake all mining activities to be viable and competitive. It must adhere to a comprehensive set of rules of regulations.

GENERAL PRINCIPLES

Most states have comprehensive environmental regulations for the mining industry. Federal regulations aimed directly at the mining industry have not yet been put into place, but broad-based statutes such as the Clean Water Act, Clean Air Act, National Environmental Policy Act, and numerous others apply to mining activities. Further, the federal government has been addressing the cleanup of historic mine wastes through its Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA, otherwise known as Superfund). More recently, the U.S. Environmental Protection Agency (EPA) has used CERCLA to address active mining operations. There is no evidence that this attention from the general public or the regulators will diminish, and mining companies in the United States can expect an ever-increasing level of scrutiny and control over their operations.

Proper concern and regard for the environment is one of the fundamental elements of any successful business strategy. Given the increasing level of attention to environmental issues in the mining business, it is even more critical today, as illustrated by the experience of Kennecott Corporation. Kennecott Corporation—a wholly owned subsidiary of RTZ, PLC, the largest mining company in the world—manages mining operations and exploration activities across North America, including several low-sulfur coal mines in the Powder River Basin, precious metals mines in the Southeastern and Western United States, and copper mines in Wisconsin and Utah. Kennecott is best known for its Bingham Canyon copper mine near Salt Lake City, which generates one-sixth of the total U.S. copper production. Kennecott's environmental strategy is based on an environmental policy that builds from a foundation of compliance with the legal, regulatory, and consent requirements of the countries and localities in which it operates. The firm's environmental policy attempts to strike a balance between society's need for metals and an environmentally sound approach to operations.

In general, the company's environmental policy dictates that its operations go beyond simply meeting current regulatory standards. The operations must exemplify best contemporary practice for the minimization and, where feasible, elimination of adverse environmental effects. The company does so by

- incorporating environmental matters as a basic part of short- and long-range planning for all projects and operations;
- complying with all applicable environmental laws, regulations, and prescribed standards and criteria, and ensuring that its contractors do likewise;
- participating in the development of environmental legislation;
- promoting and, where feasible, implementing new or more effective practices for environmental protection, compliance, and emergency response;
- taking reasonable measures to ensure that Kennecott operations are responsive to the environmental needs of the communities in which they operate; and
- regularly reporting Kennecott's performance on environmental matters through the Board of Directors to RTZ, PLC, Kennecott's parent corporation based in London.

POLICY IMPLEMENTATION

Kennecott's environmental policy is administered by the vice president of environmental affairs whose responsibilities, with the cooperation and support of the other departments within the company, are the following:

- Review, approve, and monitor all environmental management and emergency response programs
- Assess, coordinate, and monitor the environmental aspects of Kennecott's projects and operations for uniform and consistent compliance with current and anticipated laws, regulations, and standards
- Direct environmental planning for and investigations of proposed projects and investments
- Direct or review and approve, as appropriate, the preparation of all environmental studies and documentation for all operations, permits, and licenses
- Evaluate applicable developments in environmental technology and waste-management practices, and provide technical assistance and guidance for management of environmental programs at each operation
- Monitor and assess trends in environmental legislation and regulation and, where appropriate, actively represent Kennecott's interests
- In conjunction with each operation or project, develop and implement community relations programs that provide open, timely, and responsive communication on environmental programs
- Inform and advise Kennecott management on environmental compliance and performance and the technical and economic implications of environmental programs and developments
- Develop and maintain a continuing education and training program in environmental matters for all staff

The managers of all operations, projects, or activities are responsible for carrying out this policy in accordance with the direction and guidance of the vice president of environmental affairs.

KENNECOTT UTAH COPPER

As the flagship of Kennecott's operations, Kennecott Utah Copper (KUC) provides a good example of this environmental strategy in action in a large mining operation. KUC occupies over 92,000 acres in the Oquirrh Mountains just west of Salt Lake City. Operations include the Bingham Canyon Mine, the Copperton and North Concentrators, the Magna Tailings Impoundment, the Garfield Smelter and Refinery, the Utah Power Plant, and miscellaneous support facilities (Figure 1). KUC produces over 300,000 tons of copper, 500,000 ounces

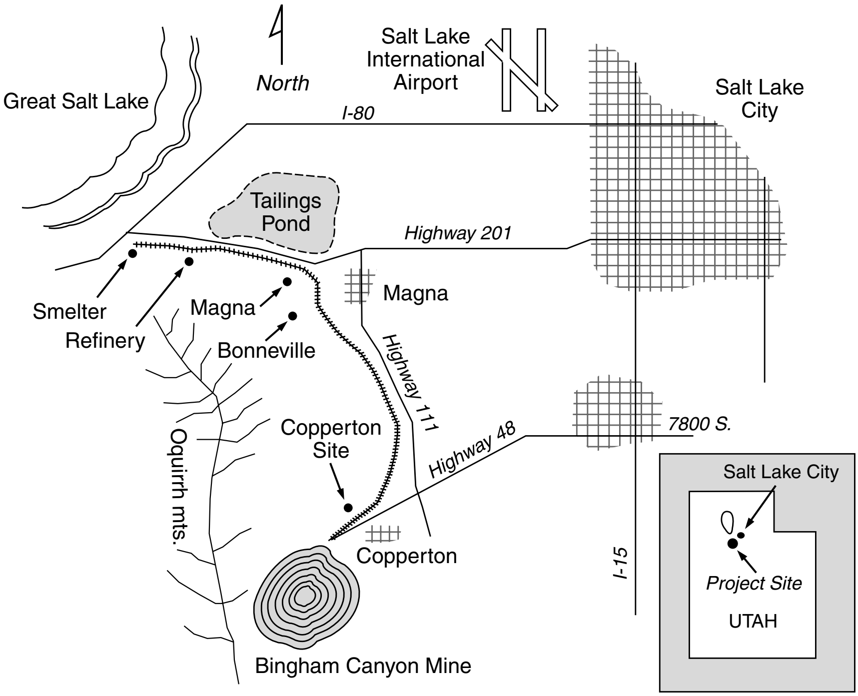

FIGURE 1 Kennecott Utah Copper operating facilities.

of gold, and 4 million ounces of silver annually with a gross market value exceeding $800 million. KUC is in the midst of a major modernization program representing an investment of nearly $2 billion. When complete, the program will ensure that KUC remains one of the world's cleanest and most efficient copper producers well into the next century. Environmental considerations are an integral part of the modernization program. In addition to designing modernized operating facilities to achieve very high levels of operating efficiency and environmental control, the modernization program includes the cleanup of historic waste sites.

Accompanying the modernization program are routine efforts to improve environmental performance in many areas, such as employee and community education, hazard elimination (e.g., elimination of underground storage tanks and polychlorinated biphenyl compounds), substitution of environmentally sound products (e.g., detergents for chlorinated solvent cleaning solutions), and extensive waste-minimization and recycling efforts. In all areas, Kennecott is attempting to stay ahead of the regulatory agencies in determining the pace and priorities of the cleanup program.

Bingham Canyon Mine and Concentrators

The first $400 million component of the modernization program, completed in 1988, included in-pit ore crushing and new grinding and flotation facilities north of Copperton near the mouth of Bingham Canyon. Transportation improvements included a 5-mile ore conveyor system and the installation of three pipelines to replace the outdated railroad ore and waste rock haulage system. The project incorporated some of the largest state-of-the-art crushing, conveying, grinding, flotation, and filtration equipment available in the industry. In 1992, the first stage of the modernization program was supplemented with the construction of the fourth grinding line at Copperton. Along with several other improvements, this program represented an additional investment of over $200 million.

The modernization of the Bingham Canyon Mine allows KUC to produce nearly 152,000 tons of ore per day. An equivalent amount of waste rock is removed from the mine each day. Ore and waste rock are transported within the pit to the adjacent waste rock disposal areas by haul trucks with capacities as large as 240 tons. About 80 percent of the ore is hauled to the in-pit crusher and then conveyed to the Copperton Concentrator for grinding and flotation. The remaining ore is loaded on rail cars for transport to the older North Concentrator. Tailings (the sandy residue left after metals are stripped from ore) are delivered by gravity pipeline from the Copperton Concentrator to a 5,700-acre storage impoundment located 12 miles to the north along the shore of the Great Salt Lake. Concentrate slurry is piped nearly 18 miles from Copperton to the Garfield Smelter.

The modernization program at the mine and concentrators improves environmental performance primarily by making the operations among the most efficient in the world. In this regard, the modernization represents a win-win situation in which operating considerations are entirely compatible with environmental protection and improvement. Such energy-efficient operations achieve the highly desirable goal of both direct and indirect pollution prevention. Water conservation and recycling were designed as integral parts of the modernization effort. As plans move forward for developing additional tailings storage capacity, environmental considerations are playing a major role in site identification, selection, and design, and the acquisition of permits for the sites.

Garfield Smelter and Refinery

In March 1992, Kennecott announced plans to complete the modernization of its operating facilities with the construction of state-of-the-art smelting and refining facilities. This component of the modernization program represents an investment of $880 million, making it the largest private investment ever undertaken in Utah. The most dramatic environmental improvement will come with the reduction of sulfur dioxide emissions from the current level of about 3,700 pounds per hour to 200 pounds per hour. Of the sulfur contained in the concentrate feed, 99.9 percent will be captured, compared with the current, very respectable capture efficiency of about 93 percent. This translates to a sulfur dioxide emission rate of about 6 pounds per ton of copper produced, which is lower than the world's cleanest smelters now operating in Japan. These improvements will be achieved even though the smelting capacity will nearly double, enabling the modernized smelter to handle all of the concentrate produced from the Bingham Canyon Mine.

Water usage will be reduced fourfold through an extensive recycling program. Pollution prevention, workplace safety and hygiene, and waste minimization are being incorporated into all aspects of the design. The smelter will generate 85 percent of its own electrical energy through steam recovery from the furnace gases and emission-control equipment, eliminating the need to burn additional fossil fuel to provide power. The new facility will require only 25 percent of the electrical power and natural gas now used to produce copper.

The refinery modernization will improve plantwide efficiency, including energy efficiency. For example, the existing direct-current electrical system will be replaced by motor-generator sets with high-capacity solid state rectifiers. An ion exchange system will be added to control impurities, and the precious-metals refinery will be replaced with a simpler, faster hydrometallurgical process. The materials handling system will be updated to simplify and mechanize the flow of work.

Waste generated from the existing smelting and refining process consists of weak acid from smelter off-gas scrubbing, flue dust, and electrolyte bleed from the refinery. All of these materials will be processed in a new hydrometallurical plant to recover valuable products, thereby maximizing resource recovery while minimizing the amount of waste that will require off-site disposal. The existing wastewater treatment plant and sludge storage ponds will become obsolete and will be reclaimed. The smelter modernization program also includes plans to segregate storm water from process waters, reducing water management problems and once again allowing the natural storm flows from drainages above the smelter to enter the Great Salt Lake.

HISTORIC WASTE SITE CLEANUP

The KUC property has a long history of mining activities dating to the 1860s, when the first lead, zinc, silver, and gold mining began in Bingham Canyon. Because the level of attention given to environmental matters in those early periods was not as great as today, there is a legacy of historic waste sites at and around KUC. The historic waste sites are primarily contaminated with waste rock, tailings, sludges, and other mining waste products.

Kennecott is proceeding expeditiously to clean up these sites as part of the overall modernization effort. Through 1994, over $140 million will have been spent to remedy problems at historic sites, and several of the cleanup efforts are among the largest such projects ever undertaken. At the same time, Kennecott is working closely with the EPA and State of Utah Department of Environmental Quality to use nontraditional regulatory frameworks to oversee these voluntary cleanup efforts.

One of the first facilities to be addressed was the leach-water handling system. Acidic metals bearing leach waters are collected at the base of the waste-rock disposal areas and are processed to recover the dissolved copper. The barren leach water is then returned to the top of the waste rock disposal areas, where it is applied to leach additional metals from the rock. In the early days of mining, this acidic leach water was simply allowed to flow down Bingham Creek. Reservoirs and holding basins were constructed in the early 1900s to begin to recover metals, and flow down Bingham Creek was terminated in the 1930s. Additional leach collection system improvements were made through the years, culminating in the construction of the Largee Bingham Creek Reservoir in 1965. The reservoir held storm waters as well as leach waters. Although the base of this reservoir was constructed of low-permeability soils, it nevertheless contributed contaminants to the local groundwater system.

When Kennecott realized the seriousness of the groundwater problem, it constructed the Small Bingham Creek Reservoir to serve as the leach-water surge basin. The Small Bingham Creek Reservoir is a double-lined impoundment equipped with leak detection and groundwater monitoring systems. It was completed and placed in service in 1990 at a cost of $13.5 million. Utah issued a groundwater discharge permit for the Small Bingham Creek Reservoir in 1992.

Once the Small Bingham Creek Reservoir was placed in service, Kennecott began the cleanup of the Large Bingham Creek Reservoir. This project consisted of removing over 3 million cubic yards of sludges, tailings, and contaminated soils; segmenting and reshaping the basin; installing a state-of-the-art lining system; and upgrading the water-handling systems. The excavation work has been completed, and the sludge and tailings have been relocated to the Bingham Canyon Mine waste-rock disposal areas. The acid-contaminated soils were treated with locally obtained soils with a high calcium carbonate content, and the neutralized soils are being reused for reclamation efforts. The relocation and reclamation activities have been married with a demonstration project examining approaches to final reclamation of waste-rock disposal areas.

The Large Bingham Creek Reservoir has been divided into two major segments—zone 1 and zone 2—by construction of an intermediate dike. Zone 1 has been lined with compacted clay, a lower 60-mil high density polyethylene (HDPE) liner, a leak detection and collection layer, and an upper 80-mil HDPE liner. The liner system incorporates never-before-used electrically conductive layers for liner integrity inspection and leak detection. The sludge removal and lining projects collectively will cost in excess of $40 million.

Other improvements to the leach-water collection system include the construction of improved cutoff walls to intercept surface and subsurface leach-water flow. Each of the 22 drainages leading from the waste-rock disposal areas is being carefully studied to ensure that the geohydrologic system is well understood. Then alluvium is stripped from the drainage at the base of the waste rock. Cutoff walls keyed into competent, low-permeability bedrock are constructed to capture leach waters. These leach waters are then collected in a series of pipes and lined canals for conveyance to the copper precipitation plant. The barren waters from the precipitation plant are returned to the waste-rock disposal areas. Kennecott is beginning to experiment with wetland systems to create passive treatment mechanisms to handle excess acid-contaminated waters. The cost of the improvements to the leach-water collection system will exceed $28 million.

Major cleanup projects are also under way in the Bingham Creek drainage downstream from the mouth of Bingham Canyon. During the lead-zinc-silver mining era of the 1800s, tailings containing high concentrations of lead and arsenic were discharged directly into Bingham Creek. These tailings washed downstream to the end of Bingham Creek in the center of Salt Lake Valley. Many areas along the lower reaches of Bingham Creek have now been developed to accommodate the growing population of the region, and resident now may come in direct contact with these tailings.

Although Kennecott did not generate these mine wastes, it owns much of the land along Bingham Creek on which the tailings reside, and the companies that generated the wastes are almost all defunct. Kennecott has undertaken several voluntary efforts to assist with the cleanup of these lead tailings, including the construction of a waste repository on its property to hold the tailings. The cleanup of Bingham Creek is continuing this year with the participation of Atlantic Richfield Company (ARCO), the only other viable responsible party. ARCO inherited liability for these tailings through their purchase of Anaconda. Kennecott and ARCO are sponsoring a health study in the Bingham Creek area to demonstrate that cleanup of very low levels of contamination are not necessary, given the low bioavailability of the lead in the tailings. The Bingham Creek lead tailings removal efforts will cost nearly $40 million.

Kennecott received an Earth Day award for the cleanup of waste-rock containing lead and arsenic from the Butterfield Creek drainage at the south end of KUC. This waste rock was generated during the construction by a now-defunct mining company of a drainage tunnel. Nearly 900,000 cubic yards of waste rock were placed along Butterfield Creek in unprotected areas and were actively eroding into the stream. Butterfield Creek is used for irrigation, and Butterfield Canyon is a popular recreational area for the public, so there was some cause for concern. Kennecott excavated the waste rock and relocated it to an engineered repository at the base of the Bingham Canyon Mine waste rock disposal area. The project also included the relocation of a roadway, the stream, and a natural-gas pipeline. The cost of the project approached $5 million. The project was completed, and Butterfield Canyon was restored to its natural condition.

Another environmental cleanup of historic wastes was completed in the Lark area, immediately east of the Bingham Canyon Mine. This project consisted of the relocation of over 1.7 million cubic yards of potentially acid-generating waste rock and the reclamation of nearly 600 acres of tailings deposits. The waste-rock was transported to the Bingham Canyon Mine waste rock disposal areas (behind the leach-water collection system). Tailings were sampled and "hot spots" containing high concentrations of lead were excavated and placed in an engineered, state-approved waste repository. The remainder of the tailings contain relatively low concentrations of metals and were reclaimed by capping with soils and revegetation. The Lark project also included removal of asbestos from buildings in the area as well as the demolition of derelict structures. The cost of the Lark-area work was nearly $15 million.

These and many other major and minor environmental cleanup projects at KUC are being conducted on an expedited basis by Kennecott in advance of any formal agreements with EPA or the State of Utah. Although there is a risk that Kennecott's responses to these environmental problems will not be acceptable to the regulators, Kennecott is proceeding as rapidly as possible to implement the solutions it believes are appropriate. In all cases, Kennecott informs the regulators before work begins and provides for regular inspections of the work by the regulators and stakeholders from the local communities. Kennecott has incorporated reasonable agency and stakeholder suggestions into the cleanup programs. On a practical level, Kennecott is proceeding so quickly that the agencies are having a hard time keeping up. For example, for several of the cleanup projects described above, work was well under way before legally enforceable administrative agreements were signed with EPA to oversee the work. Fortunately, EPA technical representatives were able to conduct site inspection even without legal agreements.

As mentioned above, an aggressive community relations program has been an integral part of the cleanup program. Kennecott has encouraged local community leaders, citizen groups, labor unions, professional organizations, environmental groups, and the regulators themselves to tour the operations and the cleanup projects to see the remarkable progress being made. This tour program has been very successful, and press coverage of the cleanup projects has been very positive. As another example of the success of the community relations program, public meetings held to discuss possible solutions to a groundwater contamination problem generated essentially no adverse publicity, and comments from the public about Kennecott's environmental approach were favorable.

Kennecott had been negotiating a ground-breaking legal agreement with EPA that would have governed the comprehensive cleanup program at Utah Copper. The agreement would have deferred EPA's consideration of listing the Utah Copper facility on the National Priorities (Superfund) List in exchange for Kennecott agreeing to do at least all of the work that would have been required had Utah Copper been listed. EPA recently elected to discontinue negotiations on this agreement because several key legal terms remained unacceptable to Kennecott. EPA has now begun actions to place Kennecott on the Superfund list. Kennecott will resist this action and will simultaneously continue its waste cleanup activities. Good working relationships that have been established between Kennecott and EPA's technical representatives are expected to continue, even if an adversarial position develops over legal terms. The cleanup will be virtually complete by 1996, which is when the modernized smelter is expected to reach full production.

NOTE

1. The expression "best contemporary practice" means the best available and proven technology appropriate to the situation, taking into account economic and environmental factors. The technology is to be supported by design, construction, operating, maintenance, and management methods of the best available quality and by active assessment and training programs.

APPENDIX A*

Mining, the Environment, and Public Policy

Roderick G. Eggert

Mineral production takes place in stages. Both the principal effects of mining on the environment and the important issues for public policy in this area are perhaps best introduced within the context of these production stages.

MINERAL EXPLORATION AND MINE DEVELOPMENT

Before a mineral deposit can be mined, it must be discovered and its economic and technical viability demonstrated, this is the exploration stage. The environmental disruption caused by exploration tends to be localized and minor. Most damage that does occur can be remediated relatively easily. During initial assessment of a region's geologic potential, explorationists rely heavily on satellite images, airborne geophysical surveys, and large-scale geologic maps to study large areas of land—hundreds or even thousands of square kilometers. Environmental impacts are essentially nil.

Explorationists then narrow the focus of their search to smaller, more prom-

*Excerpted with permission from Mining and the Environment: International Perspectives on Public Policy, Pp. 1–20, R.G. Eggert, ed. 1994. Washington, D.C.: Resources for the Future.

ising areas, involving perhaps several hundred square kilometers. Typical activities include geologic mapping, geochemical sampling, and surface geophysical surveying, which are carried out on the ground without large-scale equipment. Although the environment is affected by these activites, the impacts are minor.

Only in the subsequent, subsurface examination of still smaller areas is there any appreciable environmental impact—from drilling, trenching (bulldozing a trench to examine near-surface rocks), and the associated road building to provide access for drill rigs and bulldozers. Such impacts can be mitigated, albeit at a cost, by reclaiming drill sites and trenches and by revegetating roads. In some instances, the need for roads in remote areas has been eliminated by using helicopters to deliver drilling equipment.

For every one hundred or so mineral deposits that are discovered and evaluated in detail during exploration, fewer than ten on average will be prepared for production during the second stage of mineral production, mine development. During development, mining companies design and construct mining and beneficiation facilities, arrange for financing, provide for infrastructure, and develop marketing strategies, among other activities. The environmental impacts of these activities are more significant than those resulting from exploration but much less than those of mineral production itself.

Two types of public policy are critical during mineral exploration and mine development. The first type of public policy consists of land use rules governing whether land is available for exploration and development. The second type, applicable on those lands available for mineral activities, consists of environmental rules governing permits, environmental impact assessments, and other preproduction activities and approvals that are necessary to proceed from exploration to mine development and mining—in short, the process of environmental compliance prior to mining.

Land-use rules are important because, before mining companies can undertake mineral exploration and development, they need access to prospective mineralized lands. To be sure, in situations where mineral rights are privately held, land access is gained through negotiation between interested private parties. But for most lands worldwide, mineral rights are held by governments.[1]

Explorers or miners typically gain access to these lands in one of three ways: negotiation with a government agency, competitive bidding, and—in a few cases, such as in the United States—claim staking (that is, claiming the right to explore on a first-come, first-served basis when lands are considered open for exploration unless they are specifically declared off-limits, such as for national parks or wilderness areas). Existing land-use policies have placed large tracts of land off-limits to mineral exploration and development in a number of countries, including Australia, Canada, and the United States. The desire to avoid the environmental damages of mining is an important reason behind these withdrawals of land from mineral activities.

Public policies in the second category, rules governing the preproduction process of complying with environmental rules, take a number of forms. The most common are environmental permits and environmental impact assessments. Mining companies typically are required to obtain environmental permits signifying government approval of various aspects of their mine plans, including those for reclamation, waste disposal, sewage treatment, drinking water, and construction of dams and other impoundments. Companies also often have to carry out detailed assessments of the environmental impacts of proposed mineral development, which in turn are used by governments in deciding whether to permit mine development at all.

Environmental permits and assessments are important to mining companies because they increase the time, costs, and risks associated with bringing a mine into production. Costs may rise because of expenditures on permitting and environmental assessment and on implementing changes in project design that the compliance process may require. Risks rise, from the perspective of the firm prior to mining, in the sense that governments may decide not to allow mine development after companies have spent significant sums of money on exploration.

MINING AND BENEFICIATION

Once a mineral deposit has been discovered and developed, it is ready for the next stages in the production process: mining and beneficiation. During mining, metal-bearing rock called ore is extracted from underground or surface mines. Metal concentrations in ore vary greatly, from less than 1 percent by weight for most gold deposits to over 60 percent for some iron ore deposits; most metallic mineral deposits have ore grades in the range of 1–5 percent by weight. Beneficiation, sometimes called milling, usually occurs at the mine site. During this stage, ore is processed (or upgraded) into concentrates, which will be processed still further, usually in a smelter or refinery.

Mining and beneficiation can have a variety of environmental effects.[2] The most visible effect probably is the sight of land disturbed by mining and waste disposal. The environmental damage is largely aesthetic.

To put the problem of potentially unsightly land into perspective, consider the study by Johnson and Paone (1982). They estimated that over the fifty-year period 1930-1980, only 0.25 percent of the total land area of the United States was used for surface mining, disposal of wastes from surface and underground mines, and disposal of wastes from mineral beneficiation and further processing. Coal mining represented about half of this land, with mining of nonmetallic minerals accounting for about two-fifths and of metallic minerals about one-tenth. Some 47 percent of the land affected by mining and waste disposal had been reclaimed. The figures of course would vary considerably from country to country, but the essential point is that only a relatively small amount of land is involved in mining and associated waste disposal. Mining activities use much less land than agricultural production, urban development, logging and forestry, and national parks and wilderness areas.

Mining and beneficiation account for significant fractions of the total amount of solid waste generated each year. Very crude estimates compiled by the United Nations Environment Programme (1991) indicate that mining activities, apparently in this case including oil and gas production and coal mining, account for about three-quarters of the solid wastes generated annually in Canada, one-third in the United States, one-tenth in the European Community, and one-twentieth in Japan. The substantial differences reflect differences in the size of the extractive industries relative to the total economies in these countries. More detailed data for the United States suggest that non-coal mining accounts for about one-seventh of the solid waste generated annually that is considered nonhazardous, while coal mining accounts for less than a hundredth of such wastes. Manufacturing, on the other hand, generates more than half of nonhazardous solid wastes (Office of Technology Assessment, 1992).

These volumes of waste, however, are not good proxies for the amount of actual environmental damage caused by mining and beneficiation. For this point to be clear, it is necessary to know more about the three important types of solid waste generated by mining and beneficiation. Overburden is soil and rock removed to gain access to a mineral deposit prior to surface mining. Waste rock is separated from ore during mining. Overburden and waste rock typically are deposited adjacent to a mine (or in a mine, in the case of waste rock from underground mining). Tailings are the fine waste particles that are produced during the benefication of ore and typically suspended in water. Tailings from surface mines usually are deposited in a tailings (or settling) pond, while those from underground mines are deposited in the mine itself. (In a few countries, tailings can be deposited directly into the environment.)

The amount of solid waste generated during mining and beneficiation essentially is determined by, first, the type of mine and, second, the ore grade, or concentration of metal in the rock that will be beneficiated. The type of mine is important because underground mines generate no overburden, and mining techniques are selective enough to extract ore with only small amounts of waste rock. Surface mines, on the other hand, usually generate more than twice as much overburden and waste rock as ore.

As an example, for underground copper, gold, silver, and uranium mines in the United States, the ratio of overburden and waste rock to ore, is on the order of 0.1:1 to 0.3:1. For surface mines, the ratios range from 2:1 to 10:1 on average (EPA, 1985; based on data from the U.S. Bureau of Mines).

Ore grade, the second determinant, governs the quantity of tailings generated by a beneficiation plant. An operation with ore grading 1 percent by weight, for example, will generate ninety-nine pounds of tailings for every pound of metal, assuming complete metal recovery. Actual recovery rates usually range between 90 and 100 percent, resulting in somewhat smaller volumes of tailings.

By themselves, the solid wastes of metal mining and benefication would cause little environmental damage, except aesthetically. But when surface and ground waters interact with these wastes, acid mine drainage can be created, and this is probably the most serious environmental problem of metal mining and beneficiation. When water interacts in an oxidizing environment with the sulfide minerals typical of most metal mines, sulfuric acid is created. Metals then are dissolved in the resulting acidic water. Acid mine drainage can contaminate drinking water and affect aquatic and plant life if it gets into surface or ground waters.

The nature and extent of actual environmental damage caused by solid mine wastes and, in turn, acid mine drainage vary enormously from case to case, depending on several factors. The type of mineral deposit being mined is important: sulfide-poor deposits, for example, generate less of the sulfur needed to create sulfuric acid than sulfide-rich deposits, and high-grade deposits will have fewer tailings per unit of recovered metal than low-grade deposits. Mining and beneficiation techniques are important: underground mining, as noted above, creates much smaller volumes of waste per unit of metal than does surface mining, and the higher the recovery rate during beneficiation, the smaller the amount of tailings created. Climate is important: in arid regions, there is little of the water necessary to create acid mine drainage. Location and population density are important: acid mine drainage that enters streams feeding into sources of human drinking water not only destroys fish and wildlife habitats, but also damages human health. Finally, the environmental management practices of mining companies are important: waste piles that are revegetated or in some other way sealed, for example, are much less likely to be accessible to the water necessary to create sulfuric acid.

Other environmental problems may be associated with mental mining and beneficiation. Another type of water contamination is waste-water from beneficiation plants, which may contain ore material, heavy metals, thiosalts, and chemical reagents used in beneficiation. Air pollution is limited largely to airborne dust. Underground mining may lead to subsidence. (A major area not dealt with in this excerpt is the working environment, that is, worker health and safety; readers interested in this issue are referred to Section 11 of Hartman, 1992.)

The key issues for environmental policy affecting ongoing mining and beneficiation are for the most part the same as those affecting other economic activities: What should be the standards for environmental quality and how should they be determined? What policy tools—for example, direct regulation or economic incentives—are best suited for meeting these standards? How should rules be enforced?

Two aspects of mining and beneficiation noted above, however, bear on these more general questions. First, the extent to which the amount of solid waste generated from mining and beneficiation can be reduced has significant limits. Low-grade ores by their very nature are going to generate large volumes of tailings, and surface mines are going to generate overburden because miners have to remove overlying soil and rock to get to the ore. This is not a call for complacency; rather, it suggests that efforts and policies should be aimed a those aspects of environmental degradation over which miners have some control. Examples include efforts to recycle chemical reagents used in beneficiation, to place or seal waste piles so they are less exposed to the water necessary for acid formation, and to reduce the chances that tailings ponds will leak into surrounding soil and groundwater. Moreover, incremental improvements are to be encouraged, both in beneficiation techniques to increase rates of metal recovery and in mining techniques to reduce the amount of overburden and waste rock extracted along with metallic ores.

Second, the amount of solid waste generated during mining and beneficiation is not a good indicator of the actual amount of environmental damage caused by these activities. The same mineral deposit or mine in different circumstances may generate the same amount of waste but cause substantially different amounts of environmental damage because of differences in climate, population density, or one of the other factors noted earlier. The implication for public policy is that rules need to be flexible enough to account for site-specific differences among mines and beneficiation facilities.

MINE CLOSURE AND REHABILITATION

A mine eventually reaches the end of its useful life, either because it physically depletes its ore or because economic conditions become unfavorable (costs rise or mineral prices fall). When this happens, mine closure and rehabilitation (or reclamation) occur. Underground mines typically are sealed or plugged. Surface mines, as well as waste sites for both underground and surface mines, are rehabilitated. Pits and waste piles have their slopes stabilized and may be revegetated. In some cases, acid mine drainage continues even after mining stops, requiring some type of drainage control.

The precise nature of mine closure and rehabilitation varies from place to place because of different public policies and accepted industry practices. More fundamentally, closure and rehabilitation activities vary because potential damages from closed mines vary considerably for all the reasons cited earlier, such as type of mine, climate, and proximity to population centers.

Key issues for public policy in this area are: the rehabilitation requirements; the mechanism for ensuring that appropriate closure and rehabilitation procedures are followed; and the nature of postmining liability. The rehabilitation requirements often are only vaguely or qualitatively defined: for example, mined land must be returned to a "usable condition,' to a 'stable condition,' to the 'greatest degree,' or 'equal to the level of highest previous use'" (Intarapravich and Clark, 1994). Moreover, economic considerations often seem to get short shrift when rehabilitation standards are being determined; the result can be standards levels for which the costs of rehabilitation exceed the associated benefits. Barnes and Cox (1992), for example, discuss the apparent "goldplating" of rehabilitation requirements in Australia.

The most common mechanism for ensuring that appropriate procedures are followed is a reclamation bond or fund. With a reclamation bond, mining companies put money into an escrow account or in some other way set aside money as a guarantee that they will perform the required reclamation work. The only way for a company to get the money back is to perform the required work. A critical issue for public policy is the size of the bond: high enough to ensure that mine operators actually perform the required work rather than simply forfeit the bonded money, but not so high as to discourage mining.

The nature of postmining liability is perhaps the most controversial issue affecting mine closure and rehabilitation. Subsidence and contaminated mine water are the most common sources of postmining damages for which companies may be required to pay fines or compensation. That companies should be liable for damages caused by nonprudent, negligent, and illegal activities is not controversial. But public policies sometimes define liabilities more broadly. In some cases, a company can be held responsible for damages caused by subsidence and polluted mine water, even if it acted prudently and within existing laws and regulations or was only partially responsible for the damages. A company sometimes can be held responsible for damages retroactively, following changes in laws and regulations. These broader aspects of liability are designed to encourage companies to go beyond simple compliance with existing regulations. But such broad liability has been criticized for being unfair and for discouraging investment in mining activities.

NOTES

1. Governments may hold mineral rights for one of two reasons. First, in most countries, mineral rights are held by the government regardless of who owns the surface rights. Second, in a relatively small number of countries, surface and subsurface rights are not separated, and mineral rights belong to whoever owns the surface. In these countries (which include the United States), the government holds significant mineral rights only when it is also the owner of significant quantities of land.
2. For a more extensive overview of the environmental effects of metal mining and mineral processing, see United Nations Environment Programme (1991).

REFERENCES

Barnes, P., and A. Cox. 1992. Mine rehabilitation: An economic perspective on a technical activity. Pp. 149–158 in Rehabilitate Victoria: Advances in Mine Environmental Planning and Rehabilitation. Proceedings of the Australian Institute of Mining and Metallurgy Conference. Publication Series No. 11/92.

Hartman, H. L., ed. 1992. SME Mining Engineering Handbook. 2d ed. Littleton, Colo.: Society for Mining, Metallurgy, and Exploration.

Intarapravich, D., and A. L. Clark. 1994. Performance guarantee schemes in the minerals industry: The case of Thailand. Resources Policy 20 (March):59–69.

Johnson, W., and J. Paone. 1982. Land Utilization and Reclamation in the Mining Industry, 1930–1980. Bureau of Mines Information Circular 9962. Washington, D.C.: U.S. Department of Interior, Bureau of Mines.

Office of Technology Assessment. 1992. Managing Industrial Solid Wastes from Manufacturing, Mining, Oil and Gas Production, and Utility Coat Combusion: Background Paper. OTA-BP-0-82. Washington, D.C.: U.S. Government Printing Office.

United Nations Environment Programme. 1991. Environmental Aspects of Selected Nonferrous Metals (Cu, Ni, Pb, Zn, Au) Ore Mining. A Technical Guide. UNEP/IEPAC technical report series no. 5. Paris: United Nations Environment Programme.

U.S. Environmental Protection Agency. 1985. Office of Solid Waste and Emergency Response. Report to Congress: Wastes from the Extraction and Beneficiation of Metallic Ores, Phosphate, Asbetos, Overburden from Uranium Mining, and Oil Shale. EPA/530-SW-85-033. Washington, D.C.: U.S. Government Printing Office.

Some Analytical Tools

The Industrial Green Game. 1997. Pp. 185–199.
Washington, DC: National Academy Press.

Accounting for Environmental Cost

RICHARD MACVE

Today's challenges to business to improve environmental performance come from many quarters. They arise from new legislation and government regulations, market pressures from the "green" consumer, interests of stakeholders such as investors and employees, and general public awareness focused by the activities of environmental groups and media reporting. It has become essential for companies to increase their responsibility regarding all aspects of the environment and to adapt existing practices to cause less environmental damage. Harnessing this awakening responsibility within the corporate sector is therefore a key element in any strategy for achieving the goal of sustainable development. (See, for example, Deloitte Touche Tohmatsu International et al., 1993.) Assessing the feasibility of such a strategy requires not only the resolution of scientific and engineering problems, but also attention to the political, economic, social, and organizational changes that may be needed. A key factor will be changes in the way in which businesses make decisions that affect the environment, and in this regard it is important to understand how business accounting systems and performance accountability requirements may influence corporate decision making.

An external report can be an important element of the social control of a company's internal behavior. However, for any such reporting to be substantive, it needs to be the output of an internal system of management control and reporting just as annual financial statements are the output of an internal system of management accounting and reporting. The relation between feasible measures of accountability and their effect on managerial behavior has always been problematic (Ezzamel et al., 1990). This paper[1] explores the significance of the developments that are being made in the greening of accountancy (both for external reporting and internal management decision-making and control), and outlines some of the problems that accountants face in extending these developments. The current lack of development in related internal management-reporting, decision making, and cost-accounting systems is argued to be the major inhibitor to further improvement.

ELEMENTS OF EXTERNAL REPORTING

A report of the Environment Research Group (ERG) of the Institute of Chartered Accountants in England and Wales (ICAEW) (Macve and Carey, 1992) recommended[2] that, as part of the annual reporting cycle, a U.K. company should publish details of

- the company's environmental policy;
- the identity of the director with overall responsibility for environmental issues;
- the company's environmental objectives, which should be expressed so that performance against them can be measured (environmental targets and performance as far as possible should be reported in quantifiable technical or financial terms);
- information on actions taken, including details of the nature and amount of expenditure incurred, in pursuit of the identified environmental objectives;
- the key impacts of the business on the environment and, if practicable, related measures of environmental performance;
- the extent of compliance with regulations and any industry guidelines including, if applicable, whether the company's sites are registered under the European Community's ecology-audit scheme and the details relating to applications and approvals for registration under British Standard 7750 (Environmental Management Systems);
- significant environmental risks not required to be disclosed as contingent liabilities; and
- key features of external audit reports on the enterprise's environmental activities, including those relating to particular sites.

It was also recommended that when this information is provided in a document separate from the company's annual report and accounts, the latter should contain a reference to the availability of such information.

COMPANY RESPONSES TO EXTERNAL REPORTING

Recent surveys indicate a very limited response by U.K. companies to reporting on environmental issues (Butler et al., 1992; Federation des Experts Compatible Europeans, 1993; KPMG, 1993; Macve and Carey, 1992). There are, however, some signs that the situation is improving. Over the past 3 or 4 years, it has become normal for the largest U.K. companies to include information on environmental issues in or in conjunction with their annual reports. Some of these companies provide an extensive review. Within Europe, the amount of disclosure of environmental information appears higher in Germany than in any other country (Roberts, 1991). Much of the information currently provided in the United Kingdom remains nonspecific. Emphasis is on statements of policy with relatively little quantification of technical or financial factors; quantified achievements against targets are provided by a few companies such as ICI, British Telecom (BT), and IBM-UK.

Even when quantification is provided, only a few financial implications are mentioned. For example, ICI's environmental report presents its annual environmental expenditure and gives the costs of some individual new plants. The report also refers to some of the financial savings achieved through reductions in waste, energy, and water usage. British Petroleum (BP) devoted nearly a full page of the financial review section of its 1993 annual report and accounts to environmental investment. BP estimated its 1993 operating expenditure on pollution prevention, control, abatement, or elimination to be £200 million, although its chief financial officer noted that environmental expenditure is difficult to identify because it is embedded within other day-to-day operating costs. In addition, BP charged about £160 million against profits for environmental remediation programs at service stations and other sites. Capital investment was about £250 million. In its accounting policies, BP has a section on environmental liabilities; provisions for environmental restoration stood at £345 million at the end of 1993, whereas provisions for dismantling costs stood at £1,530 million. Potential contingent liabilities also were discussed (Accountancy, 1994).

Information on environmental costs in financial statements (or notes thereto) is more common in the United States where there are Securities and Exchange Commission (SEC) and Financial Accounting Standards Board requirements relating to disclosure of such information (Macve and Carey, 1992). Over 25 percent of the U.S. companies surveyed by KPMG (1993) gave some information on environmental expenditures. There is increasing debate worldwide as to what extent more explicit guidance should be given by regulators and accounting bodies to companies on their reporting of and accounting for environmental costs.

Most of the concern regarding financial accounting has focused on issues such as the reporting of contingent liabilities for environmental restitution costs and penalties and of impairment to land and other asset values. Issues that need to be dealt with under ordinary accounting and reporting requirements differ in their environmental aspects, mainly because their potential financial impacts may prove much larger than those that companies have already faced. As such, they are of enormous potential concern to investors and lenders (and hence to regulators such as the SEC).

The fear of litigation and of raising further the level of stakeholders' expectations inhibit the adoption of more extensive environment reporting by more companies. The major inhibitor, however, is the inadequacies of internal environmental-management systems. Few companies have systems "that allow them to produce this kind of data and therefore many have a significant hurdle to jump before they can produce an environmental report for public consumption" (KPMG, 1993, p. iii).

MEETING THE NEED FOR INTERNAL SYSTEMS

Changes needed in internal systems are both organizational and technical in nature. Top-down mission statements are inadequate without a wholesale change in management culture from top to bottom and in the education, training, and incentives provided to middle managers and other employees.

To effect these changes, several steps may be taken (Macve and Carey, 1992). Management should establish clear lines of responsibility on environmental matters and give a board member overall responsibility for such issues. The company should set out its environmental policy, prioritize objectives, and develop information systems for monitoring performance. This is needed for external regulation and reporting as well as for internal decision making and control. The structure and systems adopted should be integrated within the company's mainstream management structure and systems. This is necessary to provide clear signals and incentives for action at all levels throughout the organization. There should be an internal environmental auditing program to ensure that environmental policies are being implemented properly. Companies that may suffer environmental incidents, such as oil spills, should establish procedures for managing such events.

The evidence that companies are achieving necessary internal changes is less than that for external reporting. It is not yet clear whether this is because the changes have not yet taken place or because researchers have not yet investigated them adequately.[3]

Technical Costing Changes

Conventional accounting systems may inhibit environmentally oriented actions and expenditures because the costs that are reported—and included in investment appraisal budgets—focus on the immediate direct costs of actions, processes, and products and ignore the levels of costs at which savings are most likely to occur (i.e., indirect and longer-term costs). Accounting systems also may fail to evaluate the potential benefits of environmental decisions. Thus, an exercise by the U.S. Environmental Protection Agency (EPA) and Du Pont, and a similar exercise in the United Kingdom on individual sites in the Aire and Calder Valley, showed that there are "many pollution prevention projects with paybacks of less than a year which are not being implemented," either because of competition for management attention or the difficulties of identifying the relevant causal factors (Bennett and James, 1994). A change in approach is needed if companies are to move from "end-of-pipe" clean-up solutions to preventative design.

To provide a disciplined framework for evaluating all relevant costs, EPA has developed the total cost assessment (TCA) method, and experiments have been undertaken to investigate the effect on decision making about pollution-prevention projects in the pulp and paper industry (Tellus Institute, 1992). In the two projects studied, the new recognition that costs result from not adopting the prevention measures (in particular, future liability costs and foregone energy savings for freshwater and wastewater pumping and treatment and for freshwater heating) improved the financial acceptability of the prevention investment on all normal decision criteria (net present value, internal rate of return, and payback).[4] TCA recognizes four tiers of costs: Tier 0, direct costs only; Tier 1, Tier 0 plus indirect costs (overheads); Tier 2, Tiers 0 and 1 plus legal liability costs; and Tier 3, Tiers 0 through 2 plus intangible costs and benefits.

Conventional accounting systems and evaluation procedures measure the indirect costs at Tier 1 but suffer either from not tracing these costs to processes and products or from allocating them arbitrarily, distorting their relevance (Todd, 1994). Tiers 2 and 3 may not be recognized at all.

A paradox exists here. The whole thrust of the Tellus-EPA approach is that environmental activity such as pollution prevention is in companies' self-interest. Environmental costs are also companies' costs, but companies are failing to achieve what is in their best interests (and thereby environmentally beneficial) through the inadequacies of their cost-accounting systems. Companies are thereby needlessly causing environmental damage that is in both their own and society's interest to reduce. This leads to concern that market-based incentives (such as taxes and tradable pollution licenses) may not be effective if companies are unable to recognize the relevant costs and benefits.

The approach also raises the organizational issues of why current accounting systems are inadequate. Tellus Institute (1992) points to the additional complexities of the evaluation procedures it recommends and the additional time needed to undertake them. A cultural change is needed if managers are to give sufficient priority and attention to such evaluation schemes. Without a shift in thinking, approaches like TCA will not be able to compete with other potential investments and activities or be considered as viable options in the capital budgeting process. If managers do not get over that first hurdle, there will be no opportunity for the merits of the TCA analytic procedures to be demonstrated.

TCA methodology has controversial aspects. For example, the time horizons may need to be extended to capture the most significant costs and benefits (especially relating to future liability). There is also the broader issue of whether the discount rates normally used (reflecting capital market requirements) properly reflect "social time preference" as between current and future generations (Milne, 1994; Tellus Institute, 1992).

TCA itself has been criticized as incomplete: Its Tiers 0 and 1 cover the relatively certain costs and its Tiers 2 and 3, the probable costs and benefits. However, a management thinking strategically about environmental issues and likely changes in pressures from external stakeholders should also be considering possible future costs and benefits arising from, for example, new regulatory requirements or changes in consumer perceptions. The emphasis must be on the total life cycle costs and benefits to the company[5] from current, future, and potential perspectives. Here, there is a potential link to the need for accounting to develop ways to measure impacts on the environment. Today's externalities may become internalized costs in the future, whether though regulatory or fiscal measures (Bennett and James, 1994). Companies have begun to move up the TCA tiers. Bennett and James (1994) have interviewed companies, including Rhone-Poulenc, Baxter Healthcare, and 3M, that have identified ways to save costs by expanding their identification of relevant environmental costs.

Organizational Changes

Attempts have been made to identify the organizational difficulties that inhibit such developments.[6] Apart from the additional complexity of TCA calculations (Tellus Institute, 1992), tracing relevant environmental costs may cut across traditional organizational divisions. Information may need to be collated from various functions (sales and marketing, manufacturing, purchase, supply, research and development, finance, personnel, etc.) (Houldin, 1993), and responsibility may need to be relocated.[7] For example, are decisions on environmental factors currently exclusively allocated to the legal department or to specialist environmental managers instead of being integrated across the organization (Epstein, 1994)? Such integration may alter the patterns of internal incentive structures, product profitability, and managerial responsibility. A move to a TCA-like approach, therefore, may be resisted by managers who have a vested interest in the status quo (Todd, 1994).

Therefore, positive steps, which may require external regulatory stimulus, are needed to overcome organizational inertia. It does not appear likely that this initiative will come from accountants themselves.

A recent study of the attitudes of accountants, based on a questionnaire survey of the finance directors of the 1,000 top U.K. companies (Bebbington et al., 1994), indicates that a significant proportion (over 50 percent in the case of energy issues) have introduced, or are at least thinking about introducing, some accounting (in financial or statistical terms) for environmentally related activities (in particular for energy, investment appraisal, wastes, packaging, and aspects of legal compliance). However, there are also, surprisingly, many accountants who have no plans to address or even claim never to have heard of any of these issues; two-thirds or more expressed negative views about issues such as packaging, legal compliance, environmental budgets, water pollution, recycling, contingent liabilities, remediation costs, air pollution, land pollution, sustainability and life cycle analysis (Bebbington et al., 1994). Where companies are undertaking relevant activities, the extent of accountants' involvement does not appear to be high; the mean response on a scale of 1(low) to 5(high) only rose above 3 for "disclosure in financial statements" (Bebbington et al., 1994).

By contrast, the attitudes expressed by accountants indicate enthusiasm for innovation and development of new systems, recognition of increasing regulatory demands (especially from the U.K. government and the European Community), and overall support (even if lukewarm) for companies to take on environmental responsibility, of stakeholders' rights to information about companies' environmental performance, and of the need for accountants to be involved in the preparation of such information (Bebbington et al., 1994).

Thus, the accountants' self-perception appears to conflict with their actual involvement in companies' environmental developments. The attitudes expressed correlate slightly with the actual extent of the employer organization's environmental disclosure practice. However, overall the attitudes are very homogeneous and therefore appear to reflect accountants' personalities and professional training and culture as a group. The researchers speculate that there may be aspects of the nature of professional accountancy training (which emphasizes financial measures, precision, prudence, and resistance to change—caricatured as the bean-counters who say "no") that inhibit accountants from initiating or even responding readily to change. The official pronouncements from professional accountancy bodies that encourage greater environmental activity (e.g.; Macve and Carey, 1992) have so far largely washed over accountants in practice.

Companies also seem unsure about how to use the accountants' potential contribution. Bebbington et al. (1994, p. 119) quote "a senior finance director whose company is one of the UK's leaders in responding to the environmental agenda":

> We found it extremely difficult to see how we could put these things [environmental matters] into the accounting records . . . accounting approaches encourage short-term attitudes—community investment, like environmental investment, requires a long-term attitude.

Incentives

The critical problem of performance assessment has bedeviled many environmental initiatives (Gray et al., 1993, p. 155).

> *Ex ante* control... does not guarantee success. That is, the *ex post* audit and evaluation must take explicit cognizance of the environmental criteria. This is especially difficult in highly decentralized organizations. For example, Albright and Wilson's early environmental response was to set internal best available technology not entailing excessive cost (BATNEEC)[8] across all sites. Managers soon learned, however, that if they failed to meet *financial* targets—as opposed to environmental, BATNEEC considerations—they were penalized.

Epstein (1994, p. 15) reported on innovations at Browning-Ferris Industries in the United States, where

> one-third of total compensation is at-risk pay based on performance, and the environmental component is integrated through the use of an "environmental multiplier." The amount of the individual's bonus based on business-unit and other performance variables is multiplied by an environmental performance score. Thus, employees receiving a score of 80 out of 100 on meeting the environmental objectives, receive 80 percent of their bonus. A score of less than 70 is considered unacceptable; a multiplier of 0 is assigned and the entire bonus lost. It is with such approaches that corporations can effectively change their cultures and provide for a significant change in the environmental sensitivity of all employees at all levels.

Such developments in incentives do not seem to be widespread at present. However, individuals are essential elements of the sustainable development process, both as decisionmakers in the company and as decision-makers in the government. The implication is that "sustainability can no longer be decoupled from individual responsibility" (Whelan, 1994, p. 16). If the accounting incentive-reward structure for individual organizational members is not brought into line with environmental objectives, it will be difficult for the organization as a whole to respond effectively to the environmental challenge. At Monsanto, an internal tax is imposed on all internally generated waste, thereby doubly penalizing—and doubly motivating—management responsible for waste production. Such initiatives are pointers to the kinds of developments that may be experimented with (Gray et al., 1993).

Small Firms

A particular issue, identified in a recent white paper on sustainable development (U.K. Government, 1994), is how small firms, including agricultural enterprises, are to be given incentive to adopt more environmentally responsible behaviors. Their access to information about environmental issues and opportunities may be much more restricted than that of larger firms. For such firms, cost savings from environmental investment may also differ from those for larger firms. For example, savings in labor costs may not be apparent if a firm's labor costs are a function of what the company can bear rather than the real workload (Tellus Institute, 1992), and there may be other diseconomics of scale. However, Epstein (1994, p. 18) provides the example of Hyde Tools in Massachusetts, which employs some 300 people and uses "sound business analysis to improve both its bottom line and the environment." The company has eliminated the use of toxic chemicals and reduced annual wastewater production from 29 million gallons to 1 million gallons in 3 years.

THE ROLE OF ACCOUNTING IN ENVIRONMENTAL DECISIONS

The previous sections reviewed some recent developments in external environmental reporting and adaptations to internal costing systems to better capture relevant costs for environmental decisions and refocus management's priorities. This section covers three major issues that remain problematic both in theory and in practice: whether the environmental costs to a business can be regarded as equivalent to costs to the environment; the nature of the respective roles of quantitative physical measures and financial measures; and the fundamental nature of accounting's methodology for identifying costs.

Costs of or to the Environment?

Most of the initiatives discussed above deal with environmental impacts on companies (such as the potential liabilities or asset impairments that may need to be reported in external financial statements) and the potential cost savings and other benefits that may need to be recognized if companies are to take appropriate action to reduce waste, prevent pollution, etc. By responding to these environmental impacts, companies may benefit both the environment and their own bottom line. This approach avoids conflicts between these often contradictory outcomes because the externalities that it imposes do not presently have to be internalized—through regulatory or fiscal mechanisms—as its own costs. Thus, reporting of expenditures on environmental cleanup may not signify an environmentally "friendly" company but an "unfriendly" company that is doing something to mitigate the environmental damage it is causing. Full accountability needs to extend beyond the company's own costs and revenues to capture effects on the environment, for example through emerging—but still controversial—approaches of environmental impact assessment and life cycle analysis. (See, for example, Milne, 1994.)

Clearly, given the state of the art, any such accounting is fraught with theoretical and practical difficulties (Cope and James, 1990), although pioneering attempts have been made, for example, in BSO/Origin's annual reports (Macve and Carey, 1992). Various bodies (such as the United Nations and International Institute for Sustainable Development) have called for further research and experimentation with natural resource accounts that measure the impairment of natural and environmental resources and provide, for example, a "sustainable development profit and loss statement based on sustainable development accounting principles" or an environmentally adjusted "value added statement" (Macve and Carey, 1992, p. 75). Moreover, uncertainties and measurement difficulties have not inhibited accountants from reporting intangibles that companies do benefit from, such as research and development, brands, and goodwill, when user demands or management requirements and incentives have been sufficiently strong (Arnold et al., 1992). If stakeholders are to receive a full account of a company's environmental performance, the development of an accounting for these externalities is a priority for research and practical experimentation.

Physical or Financial Measures?

"You can't manage what you can't measure."
"Change what you count and you change what counts."

The potential for quantification of targets and achievements through physical measures—tons of hazardous wastes, proportions of recyclable to nonrecyclable materials, concentrations of particulate emissions, etc.—is clear. Such measures are already illustrated in the publicly available reports on pollution control including, increasingly, companies' annual environmental reports (Collier et al., 1993). Internally, such measures may also be used as part of an array of targets and performance indicators within a balanced scorecard (Epstein, 1994). The increased use of nonfinancial measures, at least at lower organizational levels, is also a feature of modern management control systems with their focus on quality and continuous improvement and is increasingly important where organizations promote bottom-up empowerment rather than top-down control and are downsizing and flattening their structures (Epstein, 1994; Tyson, 1994). However, the power of the financial bottom line has always made it accountancy's strongest weapon, both in its apparent capability to summarize organizational performance across a diverse range of divisions, activities, and products and in its behavioral linkages to incentives and rewards (Ezzamel et al., 1990). Despite the major reorientations of management accounting systems in recent years, top managements are likely to continue to manage by the financial numbers (Tyson, 1994). The need to capture internal environmental considerations in terms of financial consequences (as in TCA) and to attempt to measure impacts on the environment financially external to the organization is a major challenge for the further development of environmental accounting (Cope and James, 1990).

Increasing quantification (whether physical or financial), however, carries its own dangers. It gives a spurious objectivity to numbers that often reflect highly subjective and judgmental assumptions and estimates. It marginalizes qualitative factors whose subjectivity is thereby further emphasized but that may be more important. The interpretation of accounting numbers remains as important as, if not more important than, the actual numbers. The numbers should provide the means to sharpen analysis and questioning but do not in themselves provide the answers and certainly not the complete answers.

THE NATURE OF ACCOUNTING COSTS

In calling for technical improvements in accounting systems to better capture environmental costs and impacts, it is necessary to understand both the limitations of accounting numbers and the power that the process of embedding a new accountability has to change managerial decision making and organizational behavior. This is illustrated by the nineteenth century development of early cost and management accounting. Since the nineteenth century, engineers, followed by accountants and more recently by managerial economists, have focused on the nature of business costs (Wells, 1978). An influential book argued that early cost management, focusing on estimates, was a common-sense and useful engineering activity that assisted management decisions (Johnson and Kaplan, 1987). However, cost management later became enmeshed in the accountants routines for systematic recording and was overlaid by the concerns of external financial reporting, thus losing its relevance. The nature of cost accounting has always been problematic. It was primarily engendered by a new managerialist concern with standards of human performance—standards that do not have the neutral objectivity of physical engineering standards, not least because human beings react to the standards by which they are appraised (e.g., by internalizing) (Ezzamel et al., 1990).

The central technical problem has always been the treatment of indirect or overhead costs, in particular in multiactivity and multiproduct firms. The practical approach was to regard overhead as just another cost, which attached to units of product as did direct costs (Wells, 1978). To find the true unit cost of a product such indirect costs needed to be allocated systematically, and the arithmetical accuracy of the calculations gave an appearance of objectivity to the resulting answers.

Engineers and accountants argued long and hard over the correct ways to carry out such allocations. Engineers favored systems that purported to identify the physical causal relationships in operation, however remote those links. This approach has recently gained a new lease of life in the activity-based costing systems that now attempt to trace costs to their cost drivers (Tyson, 1994). However, from an economic and decision-making perspective, such allocations are inherently arbitrary and largely (if not totally) irrelevant. Cost does not create value. Value is based on the interaction of supply and demand. For economic decisions, what matters is how costs will change as a result of each decision. Therefore, the concern is whether the extra costs are justified by the extra revenue or other benefits that result. Such effects of decisions are unlikely to be captured by routine reports of past costs allocated in some inherently arbitrary fashion, however arithmetically precise.[9]

The nineteenth-century engineers' concerns with identifying true total cost were therefore misplaced. The engineers' approach was believed to be a scientific approach to identifying causes and effects. This led them to defend what are essentially indefensible allocations (Wells, 1978). However, the accountants' parallel concerns in identifying true total cost reflected a different motivation, which arguably explains the accountants' later dominance in management (accompanied, at least in the United Kingdom, by higher social status and greater material rewards [French, 1994]). Their approach is best understood as focused on the development of systems of accountability and responsibility for costs and profits that would provide norms and standards of human performance. These norms and standards could be linked to incentives and internalized by organizational members, from shop-floor workers to top managers, in a reciprocal hierarchy of surveillance, control, and self-control (Ezzamel et al., 1990). The success of the approach lay not in its creation of a new scientific knowledge about costs, but in its power to stimulate successful organizational performance (a new power knowledge) (Hoskin and Macve, 1994). Cost is therefore not an objective engineering datum about a product or process; it is constructed through conventions for an economic and social purpose.

There is a continuing tension between the engineers' objective efficiency perspective and the accountants' more subjective economic and behavioral perspective on business activity and on how to control performance. This tension sometimes amounts to hostility (French, 1994). In the context of U.K. pollution control, this tension is focused in the concept of BATNEEC, whereby scientific and technical features are balanced, if not subordinated, within managerial disciplines such as cost accounting. Thus, the U.K. Department of the Environment has been characterized as strong in engineering but not in management disciplines such as accounting and as needing strengthening in these latter skills (Power, 1994).

The final challenge for environmental costing, therefore, is not just to increase the technical sophistication by which environmental factors are traced through to activities, but to construct a new accountability that is linked to real incentives. Only then can environmental performance become as culturally dominant in management for sustainable development as, for the past 150 years or so, financial performance has become in the kind of business management that has largely created environmental problems.

CONCLUSIONS

In response to various pressures, businesses have begun to report externally on their environmental policies and performance. The significance of such external reporting depends on the extent of changes in management culture and systems and on how new measures influence management decisions. The greening of accountancy involves a reappraisal of how to identify and measure the relevant costs of processes and products (such as TCA) and a redesign of incentive mechanisms. Through these changes, managerial decisions and corporate behavior may be refocused on the goal of achieving sustainable development, for example by pursuing a viable industrial ecology. Evidence suggests that organizational inertia, including the relative lack of involvement of accountants themselves, inhibits such changes.

There is a paradox: Improving environmental performance is often advocated as remedying defects in a company's assessment of its own self-interest.

This new role of accounting is embryonic. Several theoretical and practical issues need research and experimentation if its potential is to be realized. A new dimension—costs that represent environmental benefits (and vice versa)—needs to be recognized. The appropriate balance between the roles of physical and financial performance indicators is not yet established. Moreover, the fundamental relationship between accounting and management decision making has always been problematic. The nineteenth-century debates between engineers and accountants illustrate both the subjectivity of the nature of cost and the power effects of its construction as part of a new system of accountability. A reorientation of accountability to focus on environmental performance is the major challenge in the greening of accountancy.

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NOTES

1. This paper draws in part on the report (Macve and Carey, 1992) of the Environment Research Group (ERG) of the ICAEW, which was chaired by the author. Group members included accountants, auditors, academics, business managers, investment analysts, economists, and civil servants.
2. In compiling its recommendation, the ERG of the ICAEW drew on reports, such as those of the International Chamber of Commerce, the U.K. "100 Group" of Finance Directors, the International Institute for Sustainable Development (IISD), the United Nations, the European Community Commission, and others such as Deloitte Touche Tohmatsu International/IISD/SustainAbility (1993).
3. A major study currently under way in the United States on the measurement and reporting of corporate environmental performance (sponsored by the Institute of Management Accountants [Epstein, 1994]) may shed light on the extent of changes in internal systems and barriers to change.
4. Kreuze et al. (1991) and Bailey (1991) contain worked examples of TCA.
5. This should not be confused with the life cycle analysis of external environmental impacts. Analysis such as this may identify costs and benefits that may affect the company as regulations or fiscal incentives change in the future. (See, for example, Bailey, 1991.)
6. Similar failures of present cost and management accounting systems have also been identified in relation to nonenvironmental investment decisions that involve long-term benefits intangible benefits, or both—including improvements in cost and management accounting systems themselves. (See, for example, Tyson, 1994.)
7. Again, similar complexities arise in tracing costs to cost drivers in modern activity-based costing systems (Tyson, 1994).

8. BATNEEC is the criterion used by Her Majesty's Inspectorate of Pollution in the United Kingdom to assess acceptability of processes (Slater, 1994).
9. The history of cost accounting is replete with examples of situations where divisions, processes, or products appeared unprofitable under the basis of overhead allocation adopted, so that the management wisely changed the basis (Wells, 1978).

REFERENCES

Accountancy. 1994. Environmental Investment May: 101.

Arnold, J., D. Egginton, L. Kirkham, R. Macve, and K. Peasnell. 1992. Goodwill and Other Intangibles: Theoretical Considerations and Policy Issues. London: Institute of Chartered Accountants in England and Wales.

Bailey, P. E. 1991. Full cost-accounting for life-cycle costs: A guide for engineers and financial analysts. Reading 20 in Accounting and the Environment: Readings and Discussion, L. Molinaro, ed. Arlington, Va.: Management Institute for Environment and Business.

Bebbington, J., R. Gray, I. Thomson, and D. Walters. 1994. Accountants' attitudes and environmentally-sensitive accounting. Accounting and Business Research 94:109–120.

Bennett, M., and P. James. 1994. Financial dimensions of environmental performance: Developments in environment related management accounting. Paper presented at British Accounting Association Annual Conference, Winchester.

Butler, D., C. Frost, and R. Macve. 1992. Environmental issues. Pp. 53–76 in Financial Reporting 1991–1992, L. Skerratt, ed. London: Institute of Chartered Accountants in England and Wales.

Collier, J., I. Doolittle, and P. Broke. 1993. Environmental disclosures. Accountants Digest 303.

Cope, D., and P. James. 1990. The enterprise and the environment. UK CEED Bulletin 30:6–9.

Deloitte Touche Tohmatsu International/IISD/SustainAbility. 1993. Coming Clean: Corporate Environmental Reporting. London: Deloitte Touche Tohmatsu International.

Epstein, M. J. 1994. The integration of environmental measurements into management decision making. Paper presented at British Accounting Association Annual Conference, Winchester.

Ezzamel, M., K. Hoskin, and R. Macve. 1990. Managing it all by numbers: A review of Johnson & Kaplan's 'Relevance Lost'. Accounting and Business Research 78:153–166.

Federation des Experts Compatibles Europeans (FEE). 1993. Environmental Accounting and Auditing: Survey of Current Activities and Developments. Brussels: FEE.

French, E. A. 1994. Accounting Courses for UK University Undergraduate Engineering Students. Working Paper, University of Wales College of Cardiff.

Gray, R., J. Bebbington, and D. Walters. 1993. Accounting for the Environment. London: ACCA/Paul Chapman Publishing.

Hoskin, K., and R. Macve. 1994. Reappraising the genesis of managerialism: A re-examination of the role of accounting at the Springfield Armory, 1815–1845. Accounting, Auditing and Accountability Journal 7(2): 4–29.

Houldin, M. 1993. Financial management and the environment. Address to Institute of Chartered Accounts in England and Wales Annual Conference, London.

Johnson, H. T., and R. Kaplan. 1987. Relevance Lost. Boston, Mass.: Harvard Business School Press.

KPMG. 1993. International Survey of Environmental Reporting. London: KPMG.

Kreuze, J., G. Newell, and S. Newell. 1991. Cost allocation example. Reading 14 in Accounting and the Environment: Readings and Discussion, L. Molinaro, ed. Arlington, Va.: Management Institute for Environment and Business.

Macve, R., and A. Carey, eds. 1992. Business, Accountancy and the Environment: A Policy and Research Agenda. London: Institute of Chartered Accounts in England and Wales.

Milne, M. J. 1994. Sustainability, the environment, and management accounting. Interdisciplinary Perspectives on Accounting Conference, Manchester.

Power, M. 1994. Expertise and the construction of relevance: Accountants, science and environmental audit. Working Paper, London School of Economics and Political Science.

Roberts, C. B. 1991. Environmental disclosures: A note on reporting practices in mainland Europe. Accounting, Auditing and Accountability Journal 4(3):62–71.

Slater, D. 1994. The effect of environmental laws, regulations and international trends on environmental innovation and practice. Paper presented at Signposting The Sustainable Development Strategy, Royal Academy of Engineering, London.

Tellus Institute. 1992. Total Cost Assessment: Accelerating Industrial Pollution Prevention Through Innovative Project Financial Analysis. Washington, D.C.: U.S. Environmental Protection Agency.

Todd, R. 1994. Zero loss environmental accounting systems. Pp. 191–200 in The Greening of Industrial Ecosystems, B. R. Allenby and D. J. Richards, eds. Washington, D.C.: National Academy Press.

Tyson, T. 1994. Managing for and by the numbers since mid-century: The impact of advancements in manufacturing and information technology on management accounting systems. Paper presented at the Pacioli Seminar, Institute of Chartered Accountants of Scotland, Edinburgh.

U.K. Government. 1994. Sustainable Development: The UK Strategy. Cm 2426. London: Her Majesty's Stationery Office.

Wells, M. C. 1978. Accounting for Common Costs. Urbana-Champaign, Ill.: University of Illinois Centre for International Education and Research in Accounting.

Whelan, B. 1994. Cultural and organizational factors driving good corporate practice. Paper presented at conference on Signposting The Sustainable Development Strategy, Royal Academy of Engineering, London.

The Industrial Green Game. 1997. Pp. 200–211.
Washington, DC: National Academy Press.

Public Perception, Understanding, and Values

M. GRANGER MORGAN

As with many other problems in engineering, what the public knows and thinks can have important implications for the design and the success of the various systems and activities that are loosely termed industrial ecology. This paper begins by considering when public perceptions matter and briefly discusses why they can be difficult to measure. It describes and illustrates some improved methods for measuring public perception that have recently been developed by the author and colleagues at Carnegie Mellon University (CMU) in Pittsburgh. The author illustrates how these can be used in developing public communications materials and closes by suggesting some hypotheses about public perceptions as they relate to the field of industrial ecology.

WHY DO PUBLIC PERCEPTIONS MATTER?

Suppose we can identify a set of changes in the design and operation of consumer products or in industrial process that would place fewer and lower loadings on the environment. Can we just go ahead and make the changes? In many cases the answer is yes. However, in cases where the changes require modifying public policy or public behavior, public perceptions become important and if ignored may result in the failure of technically good innovations. For example, a different regulatory approach or different regulatory priorities may be necessary. Changes in tax or other incentive structures may be necessary to induce needed behavioral changes. Government-supported research or demonstration activities may be necessary. In such circumstances, public perceptions do matter, and those trying to introduce changes ignore them at their peril.

DIFFICULTIES IN MEASURING PUBLIC UNDERSTANDING, PERCEPTIONS AND VALUES

The standard method for learning what the public knows and thinks is survey research. This method has several problems, the two most serious of which are differentiating what the respondents actually know from what they infer from the content of the questions they are asked and framing effects, which can lead to different responses depending on how the question is posed (e.g., number of lives lost vs. numbers of deaths prevented).

Standard methods for learning public values include contingent valuation and utility elicitation. The first involves posing questions about willingness to pay, either to avoid having some condition occur or to make it go away once it has occurred. The second involves asking questions about the importance that the respondent attaches to various valued attributes so as to be able to construct a normative model of choice among outcomes that involve different levels of the valued attributes. Both of these approaches suffer from the difficulty that they assume that people have well-articulated values on the questions of interest and that the problem is simply one of measuring those values. In many instances relevant to a topic such as industrial ecology, this is most unlikely (Fischhoff, 1993).

Two examples illustrate the types of problems that arise. The first has to do with the way questions are framed. A few years ago, the U.S. Environmental Protection Agency (EPA) decided to do an internal study that looked across the agency and asked, "Are we paying attention to the right set of environmental risks?" It was an internal risk-ranking exercise, but the agency also commissioned a Roper survey that gave respondents a long list of scary sounding things and asked how serious they thought each one was. *The New York Times* summarized the results as follows: "The American public and the EPA rank environmental threats quite differently with the public's fear focused most sharply on hazardous wastes sites which the government views much less serious" (Stevens, 1991). EPA's Frederick W. Allen wrote, "The most obvious reasons for the difference is that the general public simply does not have the information." EPA has argued that it is these public perceptions that have driven the agency to focus on things like Superfund, the program designed to clean up hazardous waste sites (Stevens, 1991).

The way framing works is best illustrated by the results from a different survey on the same topic that was conducted a few years later. The survey instructions asked respondents to take 7 minutes to list as many risks as they could think of. When the questionnaire was first piloted, participants voiced concerns such as "I'm worried about the risk of loosing my job", "I'm worried about the risks of my love life going on the rocks", "I'm worried about the risks of my kids flunking out of school", "I'm worried about the risks of eternal damnation", and so on. That seems like a pretty reasonable set of concerns, but it was not the set the surveyors were interested in. The instructions were revised to ask people to list risks to health safety in the environment. Respondents were then asked to identify the five risks they were most concerned about and answer a series of detailed questions about those risks.

The second approach is a very different strategy. It uses a way of framing the question different from that used in the Roper survey. The results have been published elsewhere (Fischer et al., 1991) and are summarized here. Environmental risks are a significant concern (mentioned by 44 percent of respondents compared with 23 percent who cited health risks, 22 percent who were concerned about safety, and 11 percent who noted socially based risks, such as crime). Concerns about traditional pollutants were more frequently cited than were concerns about "exotic" pollutants (21 percent vs. 13 percent). This was a three-generation study, and there were interesting generational effects. Younger people and women were slightly more concerned about the environment; everybody was worried about AIDS; middle-aged people were worried about on-the-job risks; older people were worried about things like cancer and heart attacks. In short, a picture emerged that is very different from the one from the EPA Roper survey. The general insight is that care must be taken about how questions are asked and how inferences are made from the answers.

The second example is from a study undertaken several years ago by the Chemical Manufacturers Association (CMA). CMA commissioned three of the country's leading experts in risk communication to review the literature and extract from it advice for chemical plant managers on how to communicate risk information, focusing particularly on risk comparison. On the basis of this very careful reading of the literature, the experts offered advice on good and bad ways of comparing risk (Covello et al., 1988). They concluded by providing 14 examples of text illustrating good and bad comparisons for a specific ethylene oxide plant.

These 14 pieces of text were presented in a CMU study to several different samples of Americans with the following scenario, "You have a friend. He's the manager of an ethylene oxide plant in the Midwest. He's about to get up and give a talk to a community group and here's a bunch of text that he is proposing to use. If it overlaps, he'll edit that out in the final version. Here are several factors that he's concerned about. Rank each of these pieces of text on the basis of each of those factors."

Again, the results are in the literature (Roth et al., 1990). In summary, through the use of various analytical strategies no correlation was found between the acceptability judgment predicted by the manual (i.e., by the literature), and those produced by the subjects of the survey. The insight here is not that the experts did a bad job summarizing the literature, but that even experienced professionals have limited predictive abilities with respect to the design of risk communication. There is no substitute for taking an iterative empirical approach. Studies must be done with actual people in order to see what effect the message is having; the state of the art is such that predictions cannot be made.

IMPROVED METHODS FOR STUDYING PUBLIC UNDERSTANDING, PERCEPTIONS, AND VALUES

Baruch Fischhoff, among others, has worked extensively on the problem of measuring public perceptions of risks (Kahneman et al., 1982; Slovic et al., 1980). More recently, as part of a large project on improving risk communication supported by the National Science Foundation, we have developed a method based on a "mental model" that can be useful for getting a better sense of what the public knows and thinks about issues relevant to various aspects of industrial ecology (Morgan et al., 1992).

It is easiest to illustrate how the mental model works with an example. Suppose the objective is to devise a risk-communication brochure for laypeople about radon in homes. Using the traditional approach, a radiation health physicist would be asked, "What should people be told about radon in their home?" The information would be relayed to a public relations or communications firm that would package it for a lay audience. Then, to add sophistication, the firm might be asked to evaluate the brochure's impact on public perceptions.

There are two key pieces that are missing in this traditional approach. First, what people already know about the subject is not known. People generally have some existing mental model, some knowledge structure relevant to the subject. Because anything that is told to them is going to be processed through that mental model, it is important to know what that mental model is before designing a communications strategy.

Second, people have to make decisions and choices. It is critical to know, in decision-analytic terms, what minimum information is necessary for people to make certain choices. Of course, people are not decision analysts. A number of other things matter in the communication besides the information that a conventional decision analyst would need. If that information is not supplied, the communication is going to fail at the most elementary level. Surprisingly, many risk communications fail to provide the minimum necessary information.

Our four-step approach to risk communication is based on people's mental models of risk processes. The steps are open-ended elicitation of people's beliefs about a hazard, allowing expression of both accurate and inaccurate concepts; structured questionnaires designed to determine the prevalence of these beliefs; development of communications based on both a decision-analytic assessment of what people need to know to make informed decisions and a psychological assessment of their current beliefs; and iterative testing of successive versions of those communications using open-ended, closed-form, and problem-solving instruments administered before, during, and after the receipt of messages.

The approach starts with open-ended elicitation of people's beliefs about a hazard allowing them to express both accurate and inaccurate concepts. In other words, the interviewer says to the interviewee, "Tell me about radon," and the interviewee starts talking. After a while, the interviewer says, "You said that radon comes in through the basement. Would you tell me more about that?" That is, the interviewer keeps playing back bits of information that the interviewee has already supplied and asks for elaboration. A conversation is held that may go on for some time before the interviewee has finished telling the interviewer about the subject. This is followed by a more structured portion in which the interviewer supplies a bit more information and walks the interviewee through exposure and effects processes.

This type of interview is relatively difficult to do. The first time it was done for radon, several engineering graduate students were sent out with tape recorders to interview a few of their friends. The stack of transcripts that was returned were really quite hilarious. After just a few minutes into the interview, most of the laypeople had figured out that the graduate student knew a lot about radon and were busily extracting information about radon from the interviewers. To deal with this problem, a public health nurse was hired and trained in "Eliza-like" interview techniques, that is, in techniques that do not supply any new information but simply play back details the respondent has already provided and ask for elaboration.

Interviews of this kind are an indispensable first step to find out what is in people's minds. The difficulty is that they are also very labor intensive. Twenty such interviews can result in a thick stack of transcripts; conducting enough interviews to get a statistical picture of the prevalence of these various ideas in the general population is not practical. However, it is important to get a sense of that distribution, because some of what emerges in these interviews will not be representative of general public views. If these exceptions are not sorted out, a lot of time may be invested in trying to deal with issues that are not relevant.

A similar set of interviews done on 60-hertz (Hz) electromagnetic fields is illustrative. In one of these early interviews, one respondent said something like, "Oh yeah, radiation from power lines. That happens because the radiation leaks out of the nuclear power plant and travels out along the power lines and then leaks off onto the people." We thought we had a serious problem, but later studies showed that this is not a common view (Morgan et al., 1990).

The second stage of the aproach uses a closed-form survey to determine the prevalence in the sample population of the concepts uncovered in the mental model interviews. Many of these concepts would never be imagined by investigators sitting in an office. For example, it turns out that about one-third of all Americans believe that radon in their home permanently contaminates the home and nothing can be done. Given what people know, that is not an implausible view. People have heard about long-lived radionuclides and they know about long-term contamination from pesticides. Nobody has told them and they do not understand that radon-decay products have very short half-lives. If, as the EPA did, you devise a citizen's guide to radon and mail it out by the hundreds of thousands all across the country without knowing that fact, as indeed EPA did not when they did their first version, then you have a problem. (Incidentally, EPA did know this by the time they put out their much-improved second version, because we had briefed them at length.) If this type of information is lacking when a communication is being devised, the communication will likely misfire. For example, the first EPA brochure told householders that they should measure radon. Householders believed that if they made the measurement and found a problem, there was nothing they could do about it, and if they ever wanted to sell the house they faced a moral dilemma. They may have quite rationally concluded that they would be better off not measuring.

The third stage of the approach uses the results of the mental-model interviews and an assessment of the choices people actually face to develop the best communication possible. However, it does not end there, as it is unlikely that everything will be right the first time. The message has to be subjected to careful empirical evaluation by groups of laypeople using such methods as read-aloud protocols and focus groups. This can be a bit hard on the editorial ego after much effort has been invested in devising the communication. However, in every evaluation we have run, we have found important problems that needed to be addressed.

Three examples of the opening exchanges in several mental-model interviews conducted on the topic of climate change are given in the Appendix. Note that the interviewer is careful not to supply additional information. In each case, the respondent mentions a number of specifics, each of which can be followed up on in subsequent questions.

Detailed results from our mental model studies of climate change have been published (Bostrom et al., 1994a; Read et al., 1994). The respondents in the studies regarded global warming as bad and highly likely, and many believed that warming has already occurred. Respondents tended to confuse stratospheric ozone depletion with the greenhouse effect and weather with climate. Automobile use, industrial-process heat and emissions, pollution in general, and aerosol spray cans were perceived as the main causes of global warming. The greenhouse effect was often interpreted literally to mean a hot and steamy climate. Respondents described global climate change effects that included increased incidence of skin cancer and changes in agricultural yields. Many of the mitigation and control strategies proposed focused on general pollution control and regulation, with emphasis on automobile and industrial emissions. Specific links to carbon dioxide and energy use were relatively infrequent. Respondents appeared to be relatively unfamiliar with recent regulatory developments regarding the environment, such as the ban on chlorofluorocarbons for nonessential uses, which includes use as a propellant in spray cans.

The mental-model interviews are very labor intensive. However, when the number of new concepts encountered is plotted as a function of the number of interviews, with a reasonably identified targeted audience from which respondents are drawn, the rate at which new concepts are picked up drops to a very low level after about 20 interviews.

The number of 20 interviews is borne out by formal analysis with the results of the first stage, using expert-influence diagrams and mapping the lay concepts onto the expert framing (Atman et al., 1994; Bostrom et al., 1992; Bostrom et al., 1994b). Therefore, it is probably safe after 20 such interviews to move on to the second stage.

Having identified plausible sets of concepts and misperceptions in the second stage of the process, one must determine just how prevalent they are, which requires a larger sample size. Incidentally, developing appropriate questions is sometimes not easy. For example, a series of studies on public understanding of the physics of 60-Hz electromagnetic fields (Morgan et al., 1990) shows that it is a fairly challenging job to produce questions about electromagnetic field theory that are in lay language but are precise enough to illicit an umambiguously correct answer from every physicist or electrical engineer. Expert language has a role of adding precision. Translating expert language into lay language can often be challenging.

The second stage of the mental model is best illustrated with results from the climate-change example. The results from the open-ended interviews, were used to develop a questionnaire that was administered to two well-educated samples of laypeople (177 people total). Mosts subjects did not understand that if significant global warming occurs, it will primarily result from increases in the concentration of carbon dioxide in the earth's atmosphere, and that the single most important source of carbon dioxide additions to the atmosphere is combustion of fossil fuels.

The mental model-based procedures have now been applied to a number of topics including radon in homes (Bostrom et al., 1992); 60-Hz electric and magnetic fields (Morgan et al., 1990); climate change (Bostrom et al., 1994; Read et al., 1994); dams and floods (Lave and Lave, 1991); and space launch of nuclear energy sources (Maharik and Fischhoff, 1992). In addition, Sarah Thorne of Dow Canada is making extensive use of mental-model methods to develop public communications, internally at Dow for training and to facilitate institutional change.

The traditional assumption in economics is that people have well-articulated values. Contingent valuation is a procedure for measuring those values. Much work in modern cognitive psychology and behavioral decision theory suggests that although we may have well-articulated values for things we deal with regularly, we probably do not have such values for many of the sorts of issues that are relevant in policy contexts. In these cases, Baruch Fischhoff argues that what we should be asking is, "What values would a typical member of the public construct if they were given all the relevant facts and sufficient time and support to think about them?"

Some earlier work on citizen groups advising on transmission line siting suggests that lay groups will work very hard to do a good job, and that when there is high substantive content the results may be fairly independent of group dynamics (Hester et al., 1990). Fishhoff is now running a pilot study using fuel taxes as the case context to develop new methods to help lay groups construct such values in an information-rich environment. His method alternates between individual measurement and group activities.

In work recently done for the White House Office of Science Technology and Policy to develop a procedure that federal risk-management agencies might use to rank risks (Morgan et al., 1994), the Carnegie Mellon team proposed a six-step procedure that can be summarized as follows: 1) Define and categorize the risks that will be ranked, 2) Identify the attributes that should be considered, 3) Describe the risks in terms of the attributes, 4) select the groups that will do the ranking, 5) Perform the rankings and merge the results, and 6) Provide a reasonably rich description of the results. Of course, ranking risks does not by itself solve the risk-management problem. A ranking says nothing about what it will cost to do something about risks. For this and other reasons, ranks may not translate directly into budgetary priorities.

DEVELOPING RISK COMMUNICATION MATERIALS

We have used the mental-model procedures outlined above to develop risk communication materials for the general public, including two communications on radon, four on 60-Hz fields, and one on climate change. Let us use the climate change data to illustrate how one may proceed. Society cannot have an intelligent debate on spending hundreds of billions of dollars on solutions to the specific problems of climate change unless the lay public is better informed than it is today. The clarifications needed to produce adequate public understanding are, we believe, well within the capabilities of modern risk communication.

We have just published a climate brochure that is arranged hierarchically in three levels of detail. An initial two-page spread provides a brief overview and lists and corrects common misunderstandings. Then three two-page spreads systematically explore the questions, "What is climate change?"; "If climate changes, what might happen?"; and "What can be done about climate change?" Finally, in pouches at the back of each of these three sections are detailed booklets that discuss the topic in much greater depth.

The brochure was developed from the results from our mental-model studies and an analysis of the kinds of private and public choices that laypeople face. We developed the best communication that we could, circulated it among colleagues at Carnegie Mellon, and then made extensive corrections. Next, we sent it out for review by a large number of outside experts and made an additional set of extensive revisions. At this point, we had a communication that was in pretty good shape technically but still had not been subjected to lay evaluation. To obtain such an evaluation we conducted a series of read-aloud protocol studies and conducted a number of focus groups in which the materials were reviewed section by section and line by line. These reviews resulted in a number of major revisions. For example, the overview section was added after a blue-collar evaluation group found the second-level material too substantively dense and reported that they were getting lost.

SOME HYPOTHESES ABOUT PUBLIC PERCEPTIONS AND VALUES AS THEY RELATE TO INDUSTRIAL ECOLOGY

Relatively little work on public perceptions and values in the context of industrial ecology has been done, but several general hypotheses can be advanced about what may be found when that work is done. These hypothesis are based on my own work, which utilized unpublished data supplied by the anthropologist Willett Kempton.

The first hypothesis is that the public supports improving environmental performance but primarily frames the issue in moral terms (i.e., good versus evil) and in terms of command and control (i.e., forcing people to be good). Support for the environment is shown in national poll results, and we have seen signs of the good-versus-evil thinking pattern in our mental-model interviews. Willett Kempton has reported similar results from his ethnographic and survey studies.

The second hypothesis is that the public thinks of energy conservation as morally correct, a way to save money, and requiring sacrifice. Often the link between conservation and reduced emissions of pollutants or carbon dioxide is not made. Both Kempton and we at CMU have seen evidence for this view in our open- and closed-form studies.

A correlate to hypothesis 2 is that the public associates environmental protection with sacrifice. At least in this context, people do not recognize that alternative designs can result in similar or better services or products with much lower externalities. This is supported by unpublished survey data provided by Kempton (personal communication).

The third hypothesis is that the public does not clearly see taxes as a plausible vehicle for inducing desired environmental behaviors. The public believes that the price elasticity for goods such as gasoline is close to infinite. At least in this context, little understanding is shown of the difference between short- and long-run elasticity. We have seen hints of this in our various mental-model interview transcripts; there is clear evidence in our results on carbon taxes. Kempton et al. (1995) report specific findings that support the hypothesis in the context of fuel taxes.

A Dow Jones wire story (Goldman, 1994) reported on a survey of 22,516 readers who looked at 300 “green” advertisements that have run in 186 journals since 1991. They survey found that appeals to the general good can misfire and advised advertisers to be specific about products’ benefits in terms of the consumer, not society in general, and exploit the inherent visual power of environmentalism.

A further commentary on market signals is that current residential energy bills send relatively few disaggregated market signals. Kempton and Layne (1994) studied customer use of information in such bills and noted more extensive data collection and analysis by residential consumers than one might expect and clear limits to the inferences consumers can make with existing data. They concluded that there is a need for better data and analysis and that customers would use these if they were provided.

Richard Sonnenblick and Mark Levine of Lawrence Berkely Laboratory studied two major demand-side management-incentive programs involving electric lighting (Levine and Sonnenblick, 1994). They found high levels of participant satisfaction, low participant direct costs, good reduction in participant hidden costs, and substantial learning effects likely to lead to further conservation. A similar study (Eto et al., 1994) found little evidence of "take-back effect" in lighting retrofit rebate programs and clear evidence of additional energy efficiency installations by participants (spillover) and nonparticipants (free drivers), due to expanded awareness.

The fourth hypothesis suggests that because the public frames environmental problems in moral terms rather than in terms of social structure and design choices, theories based on self-interest and conspiracy will be popular and views about the possibilities for and promise of structural and system redesign will be confused.

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REFERENCES

Atman, C. J., A. Bostrom, B. Fischhoff, and M. G. Morgan. 1994. Designing risk communications: Completing and correcting mental models of hazardous processes, part 1. Risk Analysis 14:779–788.

Bostrom, A., B. Fischhoff, and M. G. Morgan. 1992. Characterizing mental models of hazardous processes: A methodology and an application to radon. Journal of Social Issues 48(4):85–100.

Bostrom, A., M. G. Morgan, B. Fischhoff, and D. Read. 1994a. What do people know about global climate change? Part 1: Mental models. Risk Analysis: 959–970.

Bostrom, A., C. J. Atman, B. Fischhoff, and M. G. Morgan. 1994b. Evaluating risk communications: Completing and correcting mental models of hazardous processes, part 1. Risk Analysis 14:789–798.

Covello, V. T., P. M. Sandman, and P. Slovic. 1988. Risk Communication, Risk Statistics, and Risk Comparisons: A Manual for Plant Managers. Washington, D.C.: Chemical Manufacturers Association.

Eto, J., E. Vine, L. Shown, R. Sonnenblick, and C. Payne. 1994. The Cost and Performance of Utility Commercial Lighting Programs. LBL-34967. Berkeley, Calif.: Lawrence Berkeley Laboratory.

Goldman, K. 1994. April 1. Wall Street Journal, B,8:1.

Fischer, G. W., M. G. Morgan, B. Fischhoff, L. Nair, and L. B. Lave. 1991. What risks are people concerned about? Risk Analysis 11:303–314.

Fischhoff, B. 1993. Value elicitation: Is there anything in there? Pp. 36–42 in The Origin of Values, M. Hecter, R.E. Mischod, and L. Nadel, eds. New York: Aldine Degruyter.

Hester, G., M. G. Morgan, L. Nair, and K. Florig. 1990. Small group studies of regulatory decision making for power-frequency electric and magnetic fields. Risk Analysis 10:213–228.

Kahneman, D., P. Slovic, and A. Tversky, eds. 1982. Judgment Under Uncertainty: Heuristics and Biases. New York: Cambridge University Press.

Kempton, W., J. S. Boster, and J. Hartley. 1995. Environmental Values in American Culture. Cambridge, Mass.: MIT Press.

Kempton, W., and L. Layne. 1994. The consumer's energy analysis environment. Energy Policy 22:657–665.

Lave, T. R., and L. B. Lave. 1991. Public perception of the risk of floods: Implications for communication. Risk Analysis 11:255–268.

Levine, M. D., and R. Sonnenblick. 1994. On the assessment of utility demand-side management programs. Energy Policy 22(10):848–856.

Maharik, M., and B. Fischhoff. 1992. The risks of nuclear energy sources in space: Some activists' perceptions. Risk Analysis 12:383–392.

Morgan, M. G., H. K. Florig, L. Nair, C. Cortds, K. Marsh, and K. Pavlosky. 1990. Lay understanding of power-frequency fields. Bioelectromagnetics 11:313–335.

Morgan, M. G., B. Fischhoff, A. Bostrom, L. Lave, and C. J. Atman. 1992. Communicating risk to the public. Environmental Science and Technology 26:2048–2056.

Morgan, M. G., B. Fischhoff, L. Lave, and P. Fischbeck with S. Byram, K. Jenni, G. Louis, S. McBride, L. Painton, S. Siegel, and N. Welch. 1994. A Procedure for Risk Ranking for Federal Risk Management Agencies. Manuscript prepared for the Office of Science and Technology Policy.

Read, D., A. Bostrom, B. Fischhoff, and M. G. Morgan. 1994. What do people know about global climate change? Part 2: Survey studies of educated laypeople. Risk Analysis, 14:971–982.

Roth, E., M. G. Morgan, B. Fischhoff, L. B. Lave, and A. Bostrom. 1990. What do we know about making risk comparisons? Risk Analysis 10:375–392.

Slovic, P., B. Fischhoff, and S. Lichtenstein. 1980. Facts and fears: Understanding perceived risks. Pp. 181–214 in Societal Risk Assessment: How Safe is Safe Enough? R. Schwing and W. A. Albers, Jr., eds. New York: Plenum Press.

Stevens, W. K. 1991. What Really Threatens the Environment? New York Times, January 29, C, 4:1.

APPENDIX

Three Examples of Opening Responses in Mental-Model Interviews on Climate Change

EXAMPLE 1

***Interviewer*: I'd like you to tell me all about the issue of climate change.**
Subject: Climate change. Do you mean global warming?

***Interviewer*: Climate change.**
Subject: OK. Let's see. What do I know. The earth is getting warmer because there are holes in the atmosphere and this is global warming and the greenhouse effect. Um . . . I really don't know very much about it, but it does seem to be true. The temperatures do seem to be kind of warm in the winters. They do seem to be warmer than in the past . . . and . . . hmm . . . That's all I know about global warming.

EXAMPLE 2

***Interviewer:* Tell me all about the issue of climate change.**
Subject: I'm pretty interested in it . . . The ice caps are melting—the hole in the ozone layer. They think pollution from cars and aerosol cans are the cause of all that. I think the space shuttle might have something to do with it too, because they always send that up through the earth, to get out in outer space. So I think that would have something to do with it, too.

EXAMPLE 3

***Interviewer:* Tell me all about the issue of climate change.**
Subject: Climate change? Like, what about it? Like, as far as the ozone layer and ice caps melting, water level raising, rain forest going down, oxygen going down because of that? All of that kind of stuff?

***Interviewer*: Anything else?**
Subject: Well, erosion all over the place. Um, topsoils going down into everywhere. Fertilizer poisoning.

***Interviewer:* Anything else that comes to mind related to climate change?**
Subject: Climate change. Winter's ain't like they used to be. Nothing's as severe. Not as much snow. Nothing like that.

The Industrial Green Game. 1997. Pp. 212–224.
Washington, DC: National Academy Press.

Consumer Perceptions of Environmentalism in the Triad

FRANÇOISE SIMON AND MARY WOODELL

Within the past decade, environmentalism has shifted from a peripheral concern to a mainstream core component of business activities in North America, Europe, and Japan (the Triad). This movement was partly stimulated by consumer pressure that varied widely across the Triad, from the high-activism countries of Northern Europe to a relatively unorganized Japan.

The evolution of consumer concerns, while showing some similarities in certain well-defined segments across the Triad, also seems to have peaked and plateaued at different times in these three regions. This phenomenon has affected to some extent the corresponding national or regional government policies.

The lack of uniformity in consumer concerns precludes the formulation and implementation of a truly global strategy for multinational companies. However, it is still indispensable to measure and monitor the level and content of consumer environmental concerns in the major Triad markets to answer the following questions:

- How do environmental concerns vary by country and region?
- How do consumers rank their own country, and how do they prioritize key issues?
- What are the levels of consumer activism and political organization in key markets?
- How do consumer attitudes translate into actual behavior?
- What is the gap between political correctness and actual change?
- How have levels and types of commitment varied over time by region?
- What is the consumer's "green IQ"?
- How does willingness to pay differ among regions?
- How are green consumers segmented across the Triad?
- What is the relative impact of advertising that uses environmental themes?

Multicountry studies by the Gallup and Roper research organizations have recently tracked some of these variations (Gallup, 1992; Roper Organization, 1992). As background for these analyses, it may be useful to review briefly the status of government policy in the major Triad markets.

VARIATIONS IN GOVERNMENT POLICIES AND BUSINESS INITIATIVES

U.S. Fragmentation

The U.S. Environmental Protection Agency (EPA) over the past decade has added to its traditional "end-of-pipe" pollution controls a focus on pollution prevention. New approaches have included building a network of prevention programs and developing partnerships with the private sector. For example, the voluntary 33/50 Program initiative to reduce emissions of 17 chemicals (including benzene, cyanide, lead, and mercury) by 33 percent by 1992 and by 50 percent at the end of 1995 was adopted by over 1,100 U.S. companies (Carra, 1993).

However, U.S. policy still remains fragmentary. In the absence of truly uniform federal legislation, some states have started to fill the void with their own measures. Several states have adopted or are considering laws similar to the 1990 California guidelines that mandate the phasing in of alternative fuels and dictate that 10 percent of all cars be emission free by 2003. It is likely that in this case, manufacturers will have to align themselves with the toughest state rules in the absence of a federal standard.

Europe: North-South Variance

Even though Europe as early as 1972 adopted the "polluter pays" principle and has since issued over 150 environmental directives, there are still considerable variations in policy among the major markets, from the aggressive standards of Germany and Scandinavia to what has been called eco-backtracking in the United Kingdom and a general lag in Southern Europe.

Even in the most advanced markets, the recent recession has had a negative effect on environmental progress. Environmental research has lost about one-third of its funding from the German federal government, and ecology now ranks third in opinion polls as a national concern—behind unemployment and increasing crime—after having topped surveys consistently since the late 1980s. Support for Die Grilnen, the Green Party, fell below the 5-percent mark in western Germany's December 1990 elections, and therefore won no seats. Two Greens were elected in eastern Germany as part of a coalition.

While environmental progress is declining, however, business is moving ahead with pathbreaking transportation technology. Mercedes-Benz, BMW, and Volkswagen are at the forefront of ecological design in car production; BMW alone spends one-third of its $845 million annual research budget on cleaner processes, and Volkswagen leads with its 3V policy (Vermeiden, Verringen, und Verworten, or prevention, reduction, and recycling). Volkswagen has set its sights on a 100-percent recycling rate despite the complexity of car materials. On the basis of its experience at a pilot dismantling plant, Volkswagen announced that it would take back its Golf model free of charge, a factor that helped Golf win the 1992 European Car of the Year award (Schmidheiny, 1992).

In addition, Germany hopes to bring the world's first magnetic levitation (maglev) train into operation by 2005. The German government has invested over $1 billion in the project. In late 1994, parliament approved a 180-kilometer track between Hamburg and Berlin (Wright, 1994a).

The total budget for the German environmental sector (private and public) is estimated at around $5 billion. This is more than double what France spends in this area (Wright, 1994b).

France itself sends mixed signals. Although a Eurobarometer 1992 survey showed that 80 percent of the population considered environmental protection "an immediate and urgent problem for Europeans" (compared with only 59 percent who did so in 1988), the two green parties (Les Verts and Generation Ecologie) only won 7 percent of the vote in the last legislative elections. Government policy is equally ambiguous. The new Barnier Law (named after the environment minister) identifying education and renewable energy as key priorities has been criticized as "a cosmetic touch-up of existing laws," and the ministry announced in August 1994 the reactivation of the controversial $4 billion Superphenix nuclear breeder reactor; France still gets 75 percent of its electricity from nuclear reactors. However, the 1994 environmental budget was increased by 9 percent over the previous year, and French business is stepping up its involvement in environmental activities. Even in the traditionally resistant automobile sector, companies such as Peugeot and Citroen are moving ahead with plans for eco-vehicles (Wright, 1994a).

Public attitudes in the United Kingdom show patterns similar to those in France: General political correctness contradicted by an unwillingness to back it through votes or "green premiums." The government's imposition of a value-added tax on domestic fuels, seen as a tentative gesture toward an energy tax, drew sharp opposition, and there is no indication that the United Kingdom will adopt the German and U.S. policies of mandatory recycling. With a few exceptions such as the Body Shop group, British business is strongly opposed to more regulations and is adopting a self-policing stance. Green audits are now becoming the norm for major companies, and the Confederation of British Industry is calling for more open corporate reporting on environmental activities. Leading companies in this area range from Shell and British Petroleum to the National Westminster Bank (Wright, 1994a).

Spain is typical of Southern Europe in that public concern remains low and legal protection remains weak in the absence of an environment ministry. Spanish business has also been slow to accept its responsibilities and, in particular, to acknowledge that it will have to invest over $12 billion between 1994 and 1999 to meet minimum European Union environmental standards.

Japan: Government-Business Inconsistencies

By the early 1970s, Japan probably had the world's most stringent regulatory regime for industrial pollution. Over the past 21 years, industrial pollution has been greatly reduced, but it has been largely replaced by city-based pollution from car emissions and waste processing. Per capita carbon dioxide emission for Japan is less than half that for the United States and, at 2.6 tons per year ranks on a par with Sweden, thanks in part to a total private-sector investment of $81 billion in pollution prevention and another $50 billion in environmental public and private funding from 1960 through 1992. The New Earth 21 program of the Ministry of International Trade and Industry (MITI) includes the world's first commercial environment technology institute, where research ranges from the development of substitutes for chlorofluorocarbons to a project for biological carbon dioxide fixation and use. Many of the MITI-funded projects hope to commercialize their products within 10 to 15 years.

Although assuming technological leadership in areas such as waste-management equipment, Japanese industry is resisting further regulation. A carbon tax was strongly opposed by companies concerned about a loss of international competitiveness, and the media have criticized Honda, Nissan, and Toyota for lagging behind the Germans in reverse-assembly, recyclability, and cleaner-process research. Japanese automakers have resisted the environment agency's guidelines for reducing nitrogen dioxide and particle emission over the next few years, and they have also opposed a joint call by MITI and the transport ministry for an 8.5 percent boost in car mileage efficiency.

The public in Japan is not the driving force of change that it is in Northern Europe. Although environmental concerns exist, they tend to be found in specific population segments and, most importantly, they do not often translate into individual action and translate even less into political activism.

CONSUMER ATTITUDES TOWARD THE ENVIRONMENT IN THE TRIAD

In keeping with disparities in public policies and industry initiatives, consumer trends in the Triad vary widely among and within regions. Information levels, priorities, purchase and postpurchase behavior, as well as willingness to pay do not show convergence, and all these factors have been affected by the economic difficulties of the early 1990s.

TABLE 1 Personal Environmental Commitment in Triad Countries (percent engaging in "green" behaviors in the past year)

Countries	Avoided Environmentally Harmful Products	Active in Environment Group	Voted and/or worked for Proenvironment Candidate
United States	57	11	19
Canada	77	12	15
Japan	40	4	14
Germany (West)	81	10	18
United Kingdom	75	10	0
Netherlands	68	7	21
Denmark	65	10	18

SOURCE: Gallup, 1992.

Levels and Types of Environmental Concerns

In the comprehensive, multicountry *Health of the Planet* survey conducted in 1992 in 22 countries, Germans (only western Germans were polled) showed, predictably, the most concern about the environment. Sixty-seven percent rated their national environmental problems as "very serious" compared with 51 percent of Americans who did so and only 42 percent of Japanese (Gallup, 1992). Perceptions of dangers at home were remarkably uniform, with air and water pollution and waste disposal topping the list. Sharper distinctions emerged in regard to global threats. Germans were much more concerned than others about global warming, ozone loss, and the rain forest, which may be due to greater activism as well as to local factors such as deforestation through acid rain (Table 1).

Expected Role of Business

Across the Triad, business is perceived to be the chief cause of environmental problems. It was named the biggest polluter in Japan, western Germany, and the United Kingdom, and was perceived to be the second largest polluter in the United States, after individual waste. When presented with a list of remedial actions, consumers also placed the onus on business: "Regulating business" or "banning product sales" came first or second everywhere in the Triad.

This unanimity strongly suggests that companies' efforts to self-regulate and publicize their achievements may be a case of too little, too late. Negative perceptions of business and the public's wish for punitive actions such as bans appear well entrenched.

Consumer Involvement

Activism, as measured by Gallup through membership in an environmental group, remains limited in the United States and Europe (7 to 11 percent of citizens belong to such a group) and almost nonexistent in Japan (4 percent belong). In keeping with consumer skepticism, purchase behavior is more clearly defined in terms of avoidance than positive choice. As many as 81 percent of Germans, 57 percent of Americans, and 40 percent of Japanese have actively avoided products perceived as harmful. Positive choices tend to occur at lower levels. A 1990 Roper survey on the U.S. environment, for instance, found that only 14 percent of Americans regularly bought products with recycled content or in refillable packaging (Roper Organization, 1990). This is linked to the current lack of ecolabeling standards, but it may also suggest that the "greenness" of a product is not in itself a purchase trigger but rather is one component of perceived overall quality.

Postpurchase behavior appears at first to show clearer patterns, but it is actually more difficult to interpret. According to Roper, in 1990, 71 percent of Americans practiced recycling. However, recycling ranges from being mandatory in some areas (particularly metropolitan suburbs and the Northeast) to nonexistent in others. Recycling rates may therefore reflect compliance with the law rather than individual commitment. Other behaviors with a potentially greater impact were resisted if they conflicted with personal freedom. Only 8 percent of Americans polled by Roper reduced car use, for example (Roper Organization, 1990).

Evolution of Consumer Concerns

Roper Starch Worldwide reported an attitude change in the United States during the period 1989-1993 (Roper Organization, 1993). Public concern about the environment apparently peaked in 1991 and has plateaued at a higher level than any previous decade. Environmental concerns may have abated for two reasons: the relatively higher salience of recession, crime, and health care in the 1990s, and the fact that environmental action has now gone mainstream, partly shifting ecology from a hot issue to a core business activity.

Purchase behavior as well as perceptions of advertising suggest increasing confusion about what constitutes a truly green brand or company. Despite their considerable expenditures on advertising with environmental themes, companies have mostly not succeeded in gaining consumers' trust. In U.S. purchase decisions, a product's environmental record ranks well below attributes such as price, quality, and past experience with the brand. Environmental image, however, is the only factor in brand choice besides price that has shown significant growth in the past 4 years (Stisser, 1994).

Environmental concerns also vary considerably across product categories and are directly related to the ease of finding substitutes. Lawn, garden, and household cleaning products topped the list of products where environmental attributes

TABLE 2 Where Green Counts: Importance of Environment in Brand Selection, Selected Products, Ranked by Category Index, 1993

Rank	Product Category	Index[a]
1	Lawn and garden products	210
2	Household cleaning products	174
3	Paper products	138
4	Gasoline	110
5	Personal-care products	80
6	Cars	78
7	Fast-food restaurants	50

[a]Average index=100.

SOURCE: Roper Organization, 1993.

affect brand choice. Categories that can be argued to have a much greater cumulative impact on the environment, such as cars and fast-food restaurants, were ranked last because of the American public's unwillingness to sacrifice independence and time savings (Table 2). Environmental considerations are most important in products where the effect on the environment is easy to see.

The ultimate measure of environment commitment is consumers' willingness to pay green taxes or a green premium on an ecologically safe product. Several studies show a consistent pattern over time. In 1988, when people surveyed were asked whether they would accept "a less good standard of living but with much less health risk," 84 percent agreed in the United States, 69 percent in Germany, and 64 percent in Japan (Louis Harris and Associates, 1988). Four years later, when asked about their willingness to pay, respondents showed a similar pattern, with 65 percent of Americans, 59 percent of Germans, but only 31 percent of Japanese in favor (Gallup, 1992).

Consumer Awareness: Variations in the Triad

For multinational companies, between-region variations in green IQ may be more challenging than within-country variations. Americans' perceptions that they are inadequately educated about the environment is confirmed by several measures. As a follow-up to the 1990 study, in late 1991 Roper released a survey testing a nationwide cross section of nearly 2,000 adults on their "green point average." Faced with 10 questions on topics ranging from global warming to biodegradable plastic, Americans received an average of only 33 of a possible 100 points. "A low score by any standard," concluded Roper. Education and income did not help; college graduates as well as upscale Americans earned average scores of only 40 points.

Knowledge of environmental topics was best concerning wilderness issues, and the largest knowledge gap was in the products area, which suggests that the Sierra Club and other groups may have been more successful than corporations in their communication strategies.

Particularly striking is the case of chloroflurocarbons. Even though they were banned in 1978 by the EPA and the Food and Drug Administration for nearly all consumer products, only 14 percent of Americans knew about the ban 14 years later. Misperceptions also apply to the main sources of waste. Although paper is by far the largest waste component across the Triad—comprising 46 percent of the waste stream in Japan, 35 percent in the United States, and 29 percent in the United Kingdom—many Americans underestimated its importance and focused on plastics instead. Plastics amount to less than 9 percent of waste in G-7 countries yet were ranked almost equal in importance to paper by Americans. These inadequacies in basic green knowledge have had a dramatic impact on products such as fast food and disposable diapers; companies such as McDonald's and Procter & Gamble faced intense consumer pressures that might have been avoided with better public information.

By contrast, several factors have helped to increase consumer awareness in Northern Europe. One milestone was the publication of *The Green Consumer,* which shot to the top of the British bestseller list in 1989 (Euromonitor Staff, 1989) The British edition, unlike the American edition, offered specific ratings for companies and products. A similar success was achieved by the guide's German equivalent, *Okologie im Haushalt.* Retail chains also played a powerful information role in Europe. Tengelmann began a campaign to win early green customers in 1984 in Germany, and in Switzerland, Migros developed a computer program to assess the life cycle impact of its packaging (Cairncross, 1992).

Impact of Green Advertising

In the United States, even though corporate and product-specific green advertising has expanded steadily, it has had relatively little effect so far. Strikingly, in a 1991 survey rating specific brands and companies, 66 percent of the 1,500 respondents could not name a single "environmentally conscious" company (Advertising Age, 1993). Of the firms named, Procter & Gamble was first, but with only 6 percent of the votes.

Two years later, the Roper green gauge survey (Roper Organization, 1993) showed a continuing pattern of skepticism. Consumers were still three times more likely to say that business is dragging its feet rather than doing a good job to protect the environment. In this context of consumer skepticism, the most effective approaches are fact based and objective or use external validation. Only 30 percent of Americans surveyed believed comparative environmental brand claims, but 54 percent trusted ads listing specific company actions in the environmental

TABLE 3 Percent of Adults Who Believe Ads with Selected Messages, 1993

Environmental Message	Percent Who Believe
Tells positive things the company is doing on social issues, the environment, etc.	54
Says the product has been approved by an environmental group	49
Says a portion of profits will go to a good cause (disease prevention, environmental groups, etc.)	43
Says the product is better than competing products for the environment	30

SOURCE: Roper Organization, 1993.

area. Almost half of those surveyed favored an ad citing an endorsement by an environmental group (Table 3).

Segmentation Patterns in the United States

Wide variations in green attitudes and behaviors suggest the existence of distinct segments in the Triad. Some surveys, such as the Harris 1988 multicountry poll, found relatively few demographic variations, particularly among age groups. Other studies have attempted to profile distinct segments. Roper in 1990 and Simmons in 1991 categorized five main clusters in the United States by commitment level. Both categorizations show a positive linkage between green commitment and higher-than-average income and education, as would be expected (Roper Organization, 1990; Simmons Market Research Bureau, 1992).

Roper's clusters are based not only on perceptions, but also on actual pro-environmental behaviors, such as recycling. The size of two most committed groups, True-Blue Greens and Greenback Greens (now collapsed into one segment), show a slight decline from 22 percent of U.S. adults in 1990 to 20 percent by 1993 (Figure 1). A second layer, termed Sprouts because of the emergence of environmental concerns in this group, showed significant growth, from 26 percent of Americans in 1990 to 35 percent in 1993. This led to a net overall increase in the number of green consumers. In 1990, fewer than half of Americans fell into the three environmentally active groups. In 1993, 55 percent did. Other surveys confirm the spread of environmental awareness to a mass audience. Two-thirds of Americans have noticed environmental claims on packaging in 1994, and half have purchased green products since 1990 (Stisser, 1993).

A slight backlash, however, has begun. The least active group identified by Roper grew from 28 percent of the population in 1990 to 32 percent in 1993 and to 37 percent in the latest survey, conducted in July 1994. This increase occurred largely at the expense of the most committed group, which lost five percentage points from 1993 to 1994 (Table 4).

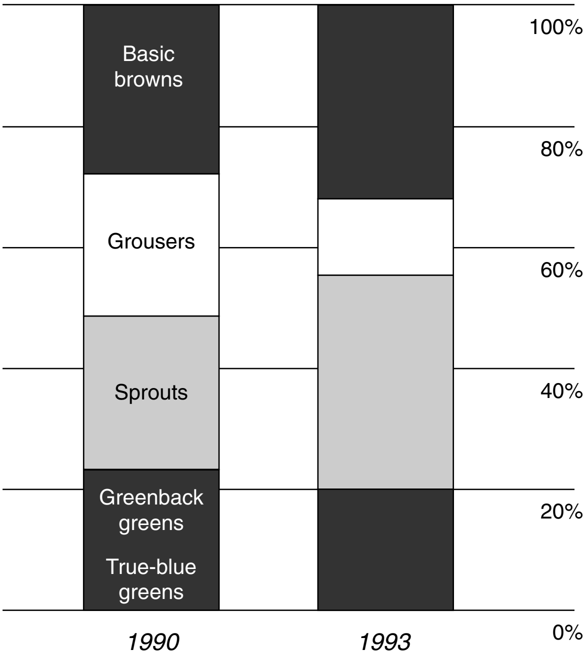

FIGURE 1 Earth's best friends. Since 1990, the three environmentally active groups have grown from 48 percent to 55 percent of all adults. Percent distribution of adults by environmental groups, 1990 and 1993. SOURCE: Roper Organization, 1990 and 1993.

TABLE 4 Environmental Consumer Segmentation: Selected Countries

	United States (%)			Index vs. United States				
	1990	1993	1994	Canada[a]	Mexico[a]	Japan[b]	Singapore[b]	Sweden[c]
True-blue/ greenback greens	22	20	15	168[d]	92	95	153[d]	305[d]
Sprouts	2	35	33	87	35[e]	86	78	115
Grousers	12	13	13	167[d]	589[d]	191[d]	182[d]	90
Basic browns	28	32	37	46[e]	37[e]	91	70[e]	5[e]

[a]Indexed against U.S. levels as measured in 1990 survey, where 100 is the base index.
[b]Indexed against U.S. levels as measured in 1993 survey, where 100 is the base index.
[c]Indexed against U.S. levels as measured in 1994 survey, where 100 is the base index.
[d]Above U.S. levels.
[e]Below U.S. levels.

SOURCE: Roper Organization, 1990, 1993, 1995.

Segmentation Trends in Europe and Japan

Sweden has the most environmentally driven population, with a massive proportion of the top two groups and an insignificant number of noncommitted consumers. (See Table 4.) Japan's top two groups are only slightly below U.S. levels, but the country has significantly more dissatisfied and apathetic consumers. Asia does not constitute a uniform bloc; Singapore, with a similar proportion of dissatisfied and apathetic consumers, has a much larger percentage of the most committed groups.

In Japan, several surveys in recent years investigated environmental awareness, but they tended to focus on consumers' views of government policies and household activities. The Green Marketing Institute (1994) developed the first Green Consumer Index (GCI) survey, which focused on consumers' views of green products, advertising, and corporate image. The survey covered a random sample drawn from a pool of nationally representative consumers and obtained responses from 1,047 residents of metropolitan Tokyo-Yokohama. The GCI survey asked respondents to rate their involvement in each of 20 activities, ranging from using recycled paper to reducing and sorting trash, accepting reduced packaging, avoiding disposables, and belonging to an environmental group.

Classification as high-green (21.9 percent), medium-green (57.8 percent), and low-green (21.9 percent) was based on points scored on the survey as well as other factors. These percentages are relative and are not comparable with those reported by Roper, which were based on different questions and classifications. Some of the demographics of the high-green segment match Western counterparts, such as the dominance of females (21.2 percent of females were high green vs. only 16 percent of males) (Figure 2).

In Japan as in the United States and Europe, greenness also increases with age and income; however, the highest Japanese green score belongs to respondents aged 50 and above, whereas the greenest American consumers are in their 40s. This may be in part because Japan's older generations, having grown up in a postwar context of scarcity, are closer to a reuse-recycle lifestyle. Another significant difference concerns education, which is positively correlated with greenness in the United States and Europe. The GCI respondents showed lower greenness as education increased.

Here again, results are influenced by the predominance of older Japanese in the greenest segment and the fact that fewer members of this group received higher education. Until recently, higher education was a strong male preserve, and males show lower levels of greenness than do females (Green Marketing Institute, 1994).

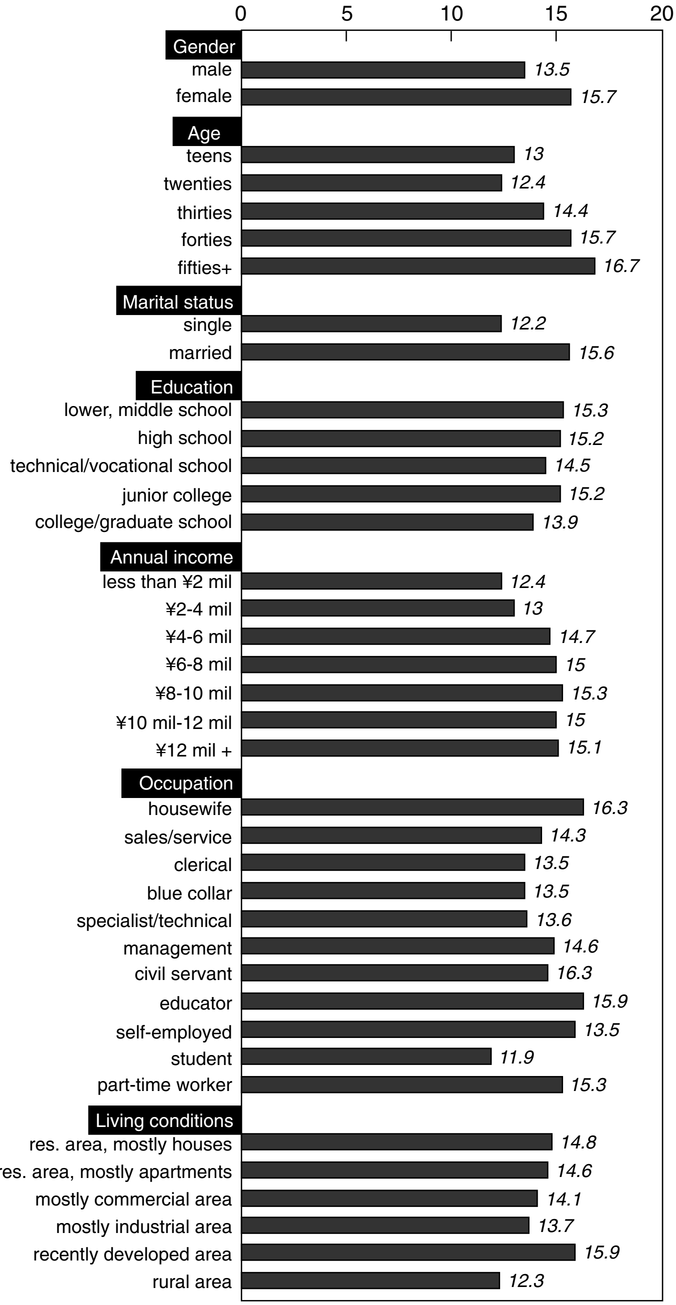

FIGURE 2 Greenness by segment of Japanase population (in percent), 1993. SOURCE: Green Marketing Institute, 1994.

CONCLUSION

Despite variations across the Triad, consumer trends show a significant convergence among the United States, Northern Europe, and Japan. In all three markets, environmentalism has been internalized by business and has become a core component of corporate strategy. In all three, consumers also continue their ecological involvement, albeit with some downward fluctuations in recent years. A core group of greenest consumers is generally growing, although not necessarily organizing through political activism. As environmentalism becomes mainstream, environmental behaviors may shift toward everyday household activities rather than highly visible political action.

Environmental factors continue to affect brand-purchase decisions and company perceptions, but some ill-conceived, premature green claims made in recent years have led to a persistent skepticism concerning green advertising. Companies will need to base any communications about the environment on objective, quantified information about tangible programs and brand attributes (such as emission reduction targets and percent recycled content). Despite policy uncertainties and fluctuations in attitudes, companies with vision, structure, and market understanding will continue to use environmental performance as a key factor of competitive advantage, as many have already demonstrated across the Triad.

REFERENCES

Advertising Age. 1993. Survey on Environmental Marketing, June 28, pp. S1–S6.

Cairncross, F. 1992. Costing the Earth: The Challenge for Governments, the Opportunities for Business. Boston: Harvard Business School Press.

Carra, J. 1993. EPA's Pollution Prevention Program Under the New Administration. Paper presented to the UNEP Conference on Business and the Environment, June 30, 1993, New York.

Euromonitor Staff. 1989. The Green Consumer. London: Euromonitor Publications.

Gallup. 1992. Health of the Planet survey. Princeton, N.J.:George H. Gallup International Institute.

Green Marketing Institute (GMI). 1994. Green Consumer Index Survey of Japan. GMI Report. No. 11, February.

Louis Harris and Associates. 1988. Public and Leadership Attitudes to the Environment in Four Continents. Survey conducted for United Nations Environmental Program, New York.

Roper Organization. 1990. The Environemnt: Public Attitudes and Individual Behavior. Survey commissioned by S. C. Johnson & Son, July 1990. New York: Roper Organization.

Roper Organization. 1991. America's Environmental GPA. Survey comissioned by S. C. Johnson and Son, November 1991. New York: Roper Organization.

Roper Organization. 1993. Green Gauge Survey. New York: Roper Organization.

Roper Organization. 1995. Green Gauge Survey. New York: Roper Organization.

Schmidheiny, S. 1992. The Business Council for Sustainable Development, Changing Course: A Global Business Perspective on Development and the Environment. Pp. 102–103, 305–308. Cambridge, Mass.: MIT Press.

Simmons Market Research Bureau. 1992. Earth Calling: Is America Listening? New York: Simmons Market Research Bureau.

Stisser, P. 1994. A deeper shade of green. American Demographics. 16(3):24–29.

Wright, M. 1994a. The state of Europe's environment, 1994. Tomorrow 1:21–29.

Wright, M. 1994b. The way ahead for Germany, Britain and France. Tomorrow 4:82–90.

The Industrial Green Game. 1997. Pp. 225–233.
Washington, DC: National Academy Press.

A Critique of Life Cycle Analysis: Paper Products

ROBERT JOHNSTON

Life cycle analysis (LCA) is a method for quantifying the environmental impact of an industrial process or product. Like some recent energy and greenhouse studies, LCA attempts to quantify or describe the environmental or energy burden of a product, process, or activity—from the extraction of raw materials, through manufacturing and recycling, to the final disposal process. The quantitative aspect of the analysis is essential in evaluating complex systems with many recycling streams, such as those encountered in the paper industry. More recently, LCAs have attempted to include an assessment or impact analysis, which presents data from the analysis as a comparative index. These results are thus more subjective and require that relative weightings or importance scales be established. Assies (1991) presents a useful introduction to the topic and highlights some general difficulties.

In Europe, the LCA movement has grown in importance, and the Society for Environmental Toxicology and Chemistry (SETAC) has set up working parties in Europe and the United States to standardize methodologies. Key SETAC workshops on the topic have taken place in Leiden, Denmark, in 1991, and Smugglers Notch, United States, in 1990 and at Gatwick, United Kingdom, in 1992.

The Gatwick conference, a European Community meeting on ecolabeling and LCA, raised the stakes for quantifying environmental impacts and seemingly connected LCA with ecolabeling. Since then, further working papers from the European Economic Community Working Group 1993 on ecolabeling indicate that the rush to complete the assessment or impact stage is proceeding despite the difficulties associated with accurately analyzing the numbers in the first place. One could interpret this as impatience on behalf of the bureaucrats with LCA, which has proved difficult and time consuming. This paper attempts to outline some of the difficulties and uncertainties that still exist.

LIFE CYCLE ANALYSIS IN THE PULP AND PAPER INDUSTRY

Several fields contribute data relevant to LCA in the pulp and paper industry. These include forestry (e.g., carbon studies of balance and sustainability), pulp and paper, and recycling (e.g., studies of fiber balance and energy-carbon dioxide); and economics (e.g., supply-demand and import-export studies). In preparing this brief review, several publications in these fields and on LCA were consulted in forestry (Adger et al., 1992; Alban and Perala, 1992; Dewar, 1990; Harmon et al., 1990; Nilsson, 1992; Sedjo, 1989; Squire et al., 1991; and Sullivan, 1992), economics (Australian Industry Commission, 1991; James and O'Neill, 1992; Pease, 1992; Wiseman, 1993; and Westernbarger et al., 1991), and in life cycle analysis (Assies, 1991; Boustead, 1990; Boustead and Hancock, 1981; Fecker, 1992; Grant, 1992; Kirkpatrick, 1992; and Lübkert et al., 1991).

THE DEVIL IS IN THE DETAILS

One factor governing the acceptability of LCAs is how much the individual industry market sectors are detailed in the study. Too much detail tends to obscure the major issues, whereas too much aggregation will produce a meaningless result. For instance, an overall model of the paper industry, such as that used by Hamm and Göttsching in their German study (1993), is unlikely to satisfy many of the specific environmental questions. Similarly, Wiseman's (1993) model of recycling in the United States fails to distinguish sufficient market sectors for it to be anything more than a crude economic tool.

Different sectoral recycling scenarios and major cross-sectoral flows in the recycling streams define minimum levels of disaggregation. The pulp and paper industry is realizing that sectoral LCA differences allow sectors to be isolated and targeted by its opponents. Hence for technical, commercial, and political reasons, there is an urgent need to ensure that the level of disaggregation is just sufficient to answer the potential queries. Studies from the international literature have varied from treating paper as a single product (Figure 1) (Hamm and Göttsching, 1993; Wiseman, 1993) to having 34 product classifications (Table 1) (Clifford et al., 1978). In Australia, there is some basic information on intersectoral fiber flows based on a five-product model that includes packaging and industrial papers, newsprint, printing and writing paper (mechanical pulp base), printing and writing paper (chemical pulp base), and tissues (B. La Fontaine, personal communication, 1992).

Some CO_2-energy studies have also been carried out on a four-product sector basis (B. La Fontaine, personal communication, 1992). Individual companies may have developed predictive models for commercial purposes that analyze

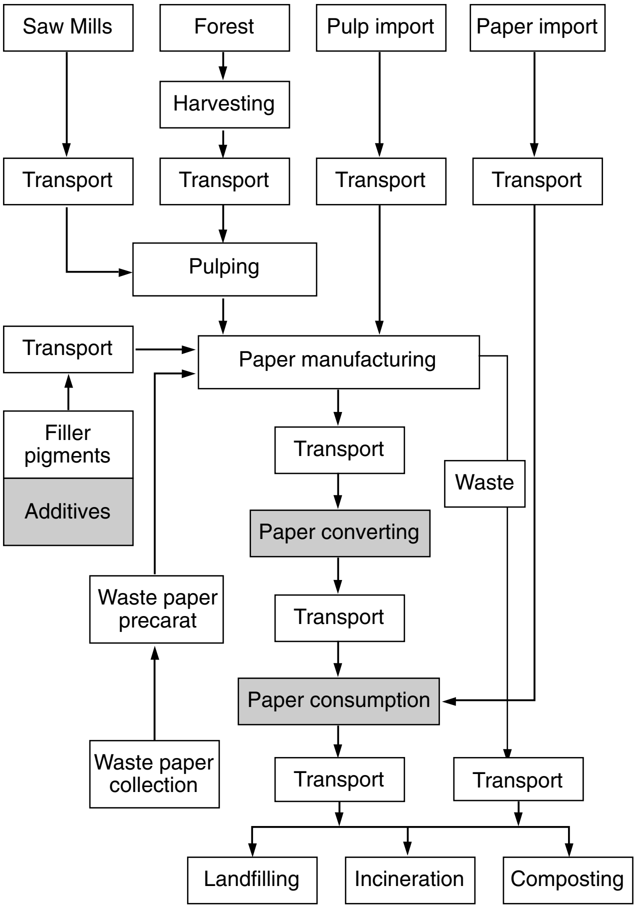

FIGURE 1 Modeling paper as a single product. Source: Hamm and Göttsching, 1993.

more detailed flows of recycled fibers into their own and competitor input streams, but if these models exist, they have not been made available for environmental analyses. The urgency of refining data is highlighted by potential environmental and commercial issues involving specific products such as liquid paper board and recycle-based copy paper. In Australia, both products have interesting histories and currently face predicaments. Liquid paper board is a difficult product to collect and recycle. In addition, it is not produced in Australia and must be imported. Thus, it is a sitting target both commercially and environmentally for attack by the local producers of plastic containers. However, the situation is not all bad—liquid paper board provides fully bleached long fiber, which is in short supply in Australia. Without the detailed data necessary for quantitative comparisons, it is difficult to move arguments away from initial superficial responses.

TABLE 1 Thirty-Four Classifications of Paper

Mineral	Stationery
Chemical wood pulp	Tissues products
Mechanical pulp	Packaging
Semichemical pulp	Corrugated board
Newsprint	Destroyed
Mechanical printings	Retained long term
Woodfree printings	Dustbin waste
Fluting	Crude mixed waste
Liner	Crude news waste
Tissue	Crude container waste
Food wrap	Crude office waste
Wrapping paper	Crude factory waste
Other paper and board	Crude printers waste
Packaging board	Group 1-4 waste
Woodfree card and board	Container waste
Newspapers and magazines	Mixed waste
Books	News waste

RECYCLING CREDITS

Credits for recycling is a major issue that has arisen in all of these analyses. Recycling can be seen as waste processing of the original product or as raw material processing for the secondary product. When recycling is carried out without intersectoral flows, there is no difference in the two viewpoints. When one product is recycled into another, however, the allocation of credits (or debits) becomes crucial. One recommendation is for a 50:50 allocation based on economic value (Assies, 1991). Recent draft papers from the European Economic Community (1993) on ecolabeling appear to completely ignore this issue.

The potential "green" advantages of recycle credits have, however, been included in business discussions within Australian and New Zealand paper companies, but no formal analysis has been published. A preliminary CO_2-energy study gave renewable energy credits to the initial product, but this appears to be an isolated occurrence (B. La Fontaine, personal communication, 1992).

RECYCLING DEGRADATION

It is surprising that no analysis appears to have considered the degradation of fibers from the wood source through pulping, paper making, and recycling operations. The concept of treating mature wood as having a (renewable) energy value *plus* fibers with an inherent paper making value would generate interesting results as the value is tracked through the life cycle. More careful analysis would be required for the technical factors involved in recycling papers containing fi-

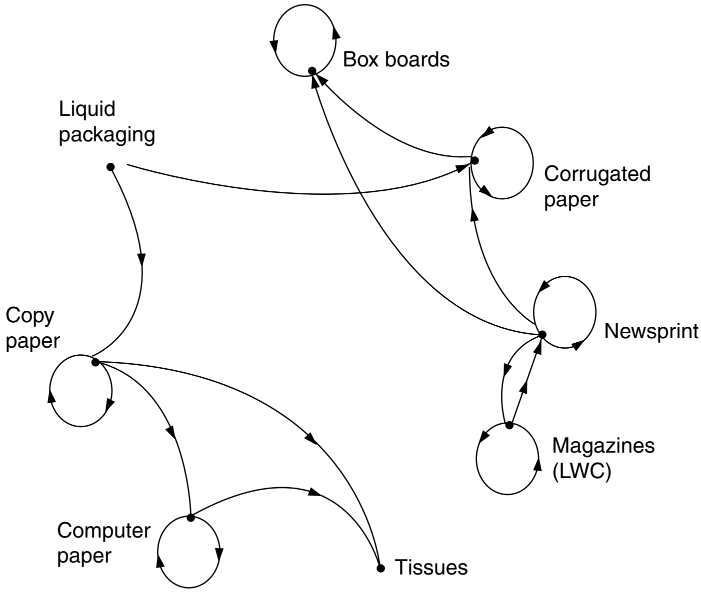

FIGURE 2 Recycling and intersectoral ecology in the paper industry.

bers with specific histories of pulping, recycling, de-inking, and so on. This is exemplified in the interconnecting recycling and reuse options in the major sectors of the industry (Figure 2).

ENERGY AND CO_2 GENERATION IN THE LIFE CYCLE

The history of LCA can be traced back to the early work of Boustead and Hancock (1981), which was primarily directed toward cradle-to-grave energy considerations. Environmental factors were added as the potential of the analytical method became obvious. More recently, the energy studies, such as by Hamm and Göttsching (1993), have been extended to include the life cycle effects of CO_2 generation or sequestering. The net CO_2 effect of all pulp and paper activities, including forestry, pulping, collection of waste paper, production of the energy used in all processes, disposal of waste, and incineration (if any), must be calculated.

One of the controversial factors common to these studies has been the consistent use of two categories of energy: renewable and nonrenewable. The major issue here is whether it is legitimate to consider some energy types to be superior to others. In older studies, for instance, hydroelectricity is generally classed as renewable and hence somewhat less critical than a nonrenewable energy source. The danger in this classification is that although an energy source may be renewable, it may not be unlimited. When all the capacity for hydroelectricity has been used, the next kilowatt-hour must be generated from nonrenewable (and CO_2-generating) resources.

Most business analysts would agree that in this case, the true marginal costs should be used: If an energy source is limited, it should not be distinguished from nonrenewable sources. Under this condition, a country's approach to nuclear energy can influence the analysis. If nuclear energy is available and programmed for expansion, one could argue (as in Hamm and Göttsching, 1993), that this source is not only renewable but also unlimited. At the margins, in this case, the next kilowatt-hour will come from renewable energy that does not produce CO_2. This situation relates directly to the boundaries of the problem—a topic referred to later in this paper.

CO_2 NEUTRALITY AND FOREST SUSTAINABILITY

The simplest summary of the carbon cycle affecting and being affected by the paper industry is shown in Figure 3 (Hamm and Göttsching, 1993). The analysis assumes CO_2 neutrality of the forestry-paper industry (i.e., that the CO_2 released by burning, composting or disposal of paper is taken up again by managed forests) and that sustainable forest management maintains a constant bank of carbon without land degradation.

The first assumption appears to be consistent with much of the literature, if long-term balance is considered. However, over a shorter term, there is undoubtedly a very real departure from balance. Certainly, composting and incineration release CO_2 on completely different time scales.

The second assumption extends outside the realm of pulp and paper and is a

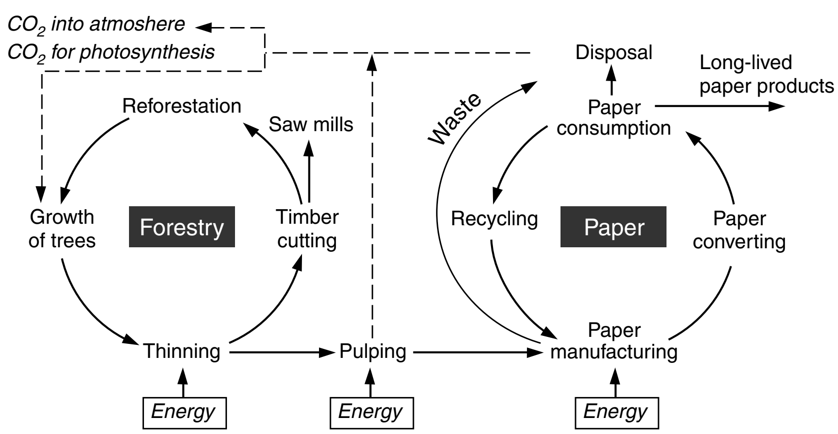

FIGURE 3 Cycle of organic carbon from wood to paper including its disposal and reuse. CO_2, carbon dioxide. SOURCE: Hamm and Göttsching, 1993.

question best left to the foresters. Nevertheless, the literature seems to indicate that factors such as rotation times and other silviculture practices can affect this assumption.

The studies referred to in this discussion vary widely in their conclusions, but all involve only northern hemisphere forests. (See particularly, Adger et al., 1992; Alban and Perala, 1992; Dewar, 1990; and Harmon et al., 1990.) In addition, these studies are primarily concerned with forests managed for timber products, with pulp wood being a by-product. The dynamics of carbon release from logged trees in this case differ widely from those of a system managed solely for pulp wood.

Even though empirical evidence suggests that overall forest stands are increasing in developed countries due to forestry management, a lack of critical data permits the assumptions noted above. In particular, specific local data are lacking (Squire et al., 1991).

An issue related to sustainability that has not been addressed in LCA studies has been the modeling of diversity over the life cycle. Once again, the forester is best qualified to quantify management policies that are conducive to maintenance of species diversity. Given that green movements such as Greenpeace have made biodiversity a high priority, it would be short-sighted for the pulp and paper industry to omit this issue.

Although it appears obvious that the industry should define the boundaries of LCA analyses so that the analysis is defensible, much of the reported work is severely limited by fuzziness around the edges. For instance, Hamm and Göttsching (1993) disregard energy requirements and CO_2 generation related to the imports required for the German industry. Göttsching (1993) appears to recognize at least the recycling interactions with Germany's major trading partners. These analyses are continuing to improve but are a long way from being definitive.

Perhaps we should not be surprised by this tendency. With limited time and limited data, it is very tempting to simply model that part of the system of most immediate concern and about which we know the most. The real danger, however, is that decision-makers using such models will be lured into making decisions that are at best suboptimal and at worst contrary to the community objectives of interest. The typical case is where legislation is introduced that, although appearing to encourage environmentally appropriate activities locally, actually causes severe problems on a more global scale. The art of modeling is, therefore, to determine just how far to extend the boundaries without creating an unnecessarily cumbersome global model.

The difficulties associated with marginal costing (discussed in the section on energy) are also related to boundary effects. Problems of this type would largely be overcome by developing the models in a linear-programming framework, such as that adopted by Clifford et al. (1978). This very innovative work, although only directed at demand and supply of waste paper, has gone largely unnoticed.

SENSITIVITY OF DATA

It would be foolish to underestimate the difficulty of obtaining adequate information for LCAs. Some of the reluctance on the part of companies to provide such information may be because much of it is basic economic process data, which have a certain business intelligence value. Recently, however, awareness of the potential power of environmental issues in market control has also been growing. Thus, individual companies are tempted to use legislation or public perceptions to gain commercial advantage. Perhaps more importantly, individual states have realized that so-called environmental legislation can provide powerful and seemingly innocent nontariff trade barriers.

This environment encourages looking at available data and closely reviewing LCA or impact-analysis reports. Getting firms to provide sufficient, accurate data will require either legislated mandates or strict neutrality on the part of the modeler.

REFERENCES

Adger, W. N., K. Brown, R. S. Shiel, and M. C. Whitby. 1992. Carbon dynamics of land use in Great Britain. J. Env. Man. 36:117.

Alban, D. H., and D. A. Perala. 1992. Carbon storage in lake states aspen ecosystems. Canadian Journal of Forest Research 22:1107.

Assies, J. A. 1991. Introductory paper to SETAC-EUROPE Workshop on Environmental Life Cycle Analysis of Products, Leiden, Netherlands, December 1991.

Australian Industry Commission. 1991. Recycling in Australia, Volumes 1 and 2. Canberra: Australian Government Publication Service.

Boustead, I. 1990. Ecobalances. Presented at the Workshop on Automotive Materials and the Environment, Stein am Rhein, Germany, November 1990.

Boustead, I., and G. F. Hancock. 1981. Energy and packaging. Chicester: Ellis.

Clifford, J. S., M. A. Laughton, T. S. McRoberts, and P. V. Slee. 1978. LP modelling in the paper industry as an aid to recycling decisions. Conservation and Recycling 2(2):97.

Dewar, R. C. 1990. A model of carbon storage in forests and forest products. Tree Physiology 6:417.

European Economic Community Adhoc Working Group. 1993. Criteria document for eco-labelling of copying paper.

Fecker, I. 1992. How to calculate an ecological balance? Report No. 22. Swiss Federal Laboratories for Material Testing and Research.

Göttsching, L. 1993. Modelling age distribution and physical characteristics of waste paper. Presented at TAPPI 1993 Recycling Symposium, New Orleans, February 1993.

Grant, R. 1992. Report on European Community Eco-labelling & Life Cycle Analysis Conference, Gatwick Omni Continental, Vancouver.

Hamm, U., and L. Göttsching. 1993. The CO_2 balance sheet—How is it affected by the German pulp and paper industry? Das Papier 46:10A.

Harmon, M. E., W. K. Ferrell, and J. F. Franklin. 1990. Effects on carbon storage of conversion of old-growth forests to young forests. Science 247:699.

Jones, D. W., and R. V. O'Neill. 1992. Land use with endogenous environmental degradation and conservation. Resources and Energy 14:381.

Kirkpatrick, N. 1992. Life cycle assessment and environmental management systems. Report No. PK/M441. Leatherhead: PIRA International.

Lübkert, B., Y. Virtanen, M. Mühlberger, J. Ingman, B. Vallance, and S. Alber. 1991. IDEA, an International Database for Ecoprofile Analysis. Working Paper 91-30. Laxenburg: IIASA.

Nilsson, S. 1992. Recommended policies for sustainability of European forest resources. Environmental Conservation 19(2):178.

Pease, D. A. 1992. Recycling new products will help cut fiber use. Forest Industries (March):29.

Sedjo, R. A. 1989. Forests to offset the greenhouse effect. Journal of Forestry 87(7):12.

Squire, R. O., D. W. Flinn, and R. G. Campbell. 1991. Silvicultural research for sustained wood production and biosphere conservation in the pine plantations and native eucalypt forests of S.E. Australia. Australian Forestry 54(3):120.

Sullivan, F. 1992. Are forests a renewable and permanent source of supply? Journal of the Institute of Wood Science 12(5):263.

Westernbarger, D., R. Boyd, and C. Jung. 1991. Welfare gains from aluminum recycling in the USA. Resources Policy 17:332.

Wiseman, C. 1993. Increased U.S. wastepaper recycling: The effect on timber demand. Resources, Conservation and Recycling 8:103.

The Industrial Green Game. 1997. Pp. 234–253.
Washington, DC: National Academy Press.

Japan's Changing Environmental Policy, Government Initiatives, and Industry Responses

SUKEHIRO GOTOH

The year 1989 was a turning point in Japan's environmental policy. The concept of sustainable development from *Our Common Future* (World Commission on Environment and Development, 1987) had taken hold, public concern about global environmental problems was growing, and global environmental issues were on the agenda at the July G7 Economic Summit meeting in Paris.

In May 1989, the Japanese government established a Council of Ministers for Global Environmental Conservation. At its first meeting, the council set forth six directives for global environmental conservation (Japan Environment Agency, 1990):

- Participate positively in formulating an international framework for protecting the global environment and promote measures from a global viewpoint
- Promote the observation (monitoring) and research of the global environment to expedite the formulation of global environmental protection, measured on the basis of scientific understanding of the effects of human activities on the global environment
- Pursue the development and transfer of technology for global environmental protection by contributing to various international efforts
- Make efforts to expand official development assistance for environmental protection through the development and transfer of appropriate technology for developing countries and the training of human resources in the environmental sector
- Strengthen environmental consideration regarding the implementation of official development assistance

- Ensure that economic activities are carried out in a manner less burdensome on the global environment by promoting resource and energy conservation, raising awareness, and improving education in all segments of the population

This government-led environmental initiative triggered related activities within industry and various Japanese ministries and agencies. Several reports were released by the Council on Industrial Structure and Policy of the Ministry of International Trade and Industry (MITI). In 1990, an interim report, *Earth Revival Program,* called for a new value concept intended to change people's lifestyles—a paradigm shift in innovative industrial technology and coordination of industrial activities and environmental policies. The new value concept placed less importance on material affluence and more on spiritual, cultural, and traditional aspects of life. The shift is not only from pollution control to prevention, but also to technologies of dematerialization—those which use less material and energy per unit product. In November 1990, the Experts' Study Committee on A Recycle-Oriented Society for Environmental Protection of the Japan Environment Agency (JEA), published a report that formed the basis for Japan's 1991 recycling law (Japanese Environment Agency, 1991).

Industry also appears to have made big changes in its environmental policy since 1989. As early as April 1990, Keidanren (a federation of economic organizations representing more than 1,000 private industry and business organizations) released a document showing industry's approach to new environmental policy (Keidanren, 1990a). For the first time, Japanese companies were required to review all their activities and operations from the viewpoint of reducing their total environmental load and, in particular, integrating all environmental precautions and considerations into their operations.

In November 1990, this was followed by another document that reviewed existing waste-management practices in major industries and proposed a new responsible upstream preventive approach (Keidanren, 1990b). This was extended in April 1991 with the consensus of the Keidanren member organization on guidelines for corporate environmental actions (Keidanren, 1991). The 24 guidelines cover 11 corporate environmental policy areas, including implementing internal environmental auditing and management, and improving environmental attributes of products (Appendix 1). Although the charter is not binding, almost all corporations, particularly leading firms, are making efforts to improve environmental performance in accordance with it.

Concurrently, the government intensified its environmental public policy efforts. On the basis of JEA's 1991 recycle society report (JEA, 1991), six ministries, including MITI, the Ministry of Health and Welfare, and JEA, worked collaboratively with industry on a bill to promote recycling. The Law Promoting the Utilization of Recycled Resources, or the recycling law of 1991, stipulates new responsibilities for promoting recycling in selected industries, of first- and second-use products, and of by-products (Yumoto et al., 1994). This responsibility includes voluntarily conducting product (life cycle) assessments for improving recyclability under the guidance of relevant government ministries. In October 1991, the government proposed the largest amendments in 20 years to the existing Waste Disposal and Public Cleansing Law. The amendments introduce waste reduction at source and separation, recycling, or both before waste generation (in Article 1, Purpose); require preliminary product assessment for proper disposability (in Article 3, Corporate Responsibility); and add corporate responsibility to recover certain waste designated by the Minister of Health and Welfare as “indisposable in nature” (in Article 6.3, Collaboration of Corporations).

To promote this upstream approach in industry, in October 1992 MITI released a guideline, *The Voluntary Plan,* and in February 1993 JEA published a similar document, *Action Program for Environmentally Conscious Cooperates.* Both guidelines align with the Keidanren (1991) *Global Environment Charter.*

The latest government environmental policy initiative is the Basic Environment Law (BEL) of November 1993. As early as in March 1993, after 15 months of formal consultation and discussion with industry, the Central Pollution Abatement Council, JEA’s Nature Conservation Council, and several different government ministries and agencies, the government sent BEL to the 126th session of the Diet. The bill’s passage into law was rocky: It was debated for 58 hours in the Lower and Upper Houses. It was due to be passed into law in June 1993, but the Lower House was dissolved suddenly in the midst of political turmoil, and the bill automatically became null. The same bill, however, was proposed to the 128th Session by the new administration and was passed on November 12, 1993.

The new legislation, in principle, is an integrated national environmental policy act that incorporates the former Basic Pollution Control Law, the Nature Conservation Law, and the government’s basic policy principles for global environmental conservation. In the context of industrial ecology, BEL includes consideration of environmental load in addition to *kogai,* or pollution; directions and goals of a future sustainable economic society, including extended corporate responsibilities; and government policies to promote and encourage corporate and other efforts to enhance environmental performance. Some articles of particular importance in this legislation are listed in Appendix 2.

THE GOAL: A GLOBAL RECYCLE SOCIETY

Many of these initiatives mirror the vision Glenn T. Seaborg, an American Nobel laureate in chemistry, had in 1974. He forecasted development of a steady state world in which resources are recycled and used with maximum efficiency. He said: “We will be creating a ‘recycle society’ . . . in which virtually all materials used are reused indefinitely and virgin resources become primarily the ‘make-up’ materials . . ..” (Seaborg, 1974). Having recognized all the constraints

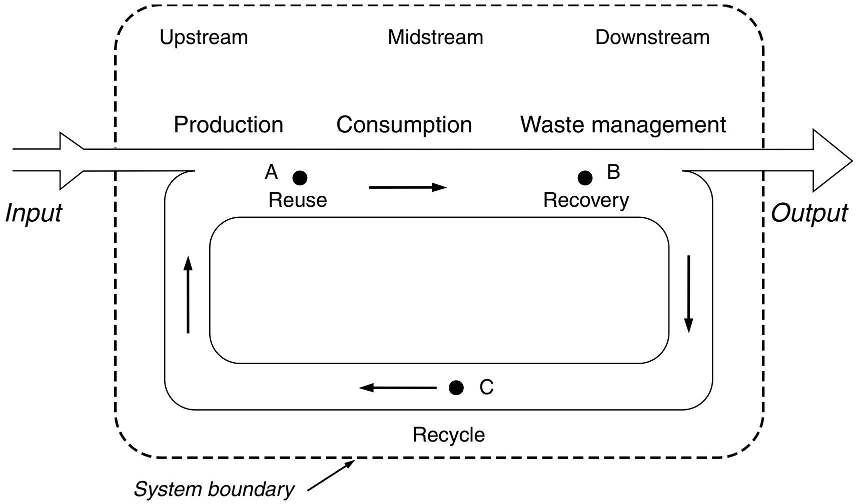

FIGURE 1 A simple model of the "recycle society."

arising from resource depletion and environmental degradation, what he envisioned was a "globally sustainable industrial society."

In fact, *Towards a Recycle Society in the 21st Century* (JEA, 1991) conceptualized a simple model of the recycle society (Figure 1). In this society, well-designed technical and economic mechanisms encourage industry and the public to seize every opportunity to recover, recycle, and reuse materials and energy as much as is thermodynamically feasible. Simultaneous frugal use and environmentally preferable selection of materials and energy sources lower the overall environmental load resulting from human activities to ensure local, regional, and global sustainable development.

In reality, however, the current economic growth of industrialized nations can hardly be characterized as environmentally sustainable. For example, the fiscal year (FY) 1990 material balance for Japan (Figure 2) shows that only 10 percent of the more than 2 billion metric tons of virgin natural resources used is recycled. The average Japanese consumes 46 times more natural resources than an Indonesian. Consumption of the world's commercial energy resources illustrates the point further. In 1990, industrialized nations, with about 22 percent of the world population, consumed about 82 percent of the world's commercial energy, which was 8.1 billion metric tons of oil equivalent (Tolba and El-Kholy, 1992). This means that, on average, a person living in a high-income country consumes 16.2 times more energy than a person living in a developing nation.

From an industrial ecology perspective, the current industrialized society, popularly referred to as the "throw-away" or "mass production, mass consumption, mass discard" society in Japan, is indeed well characterized by linear flows

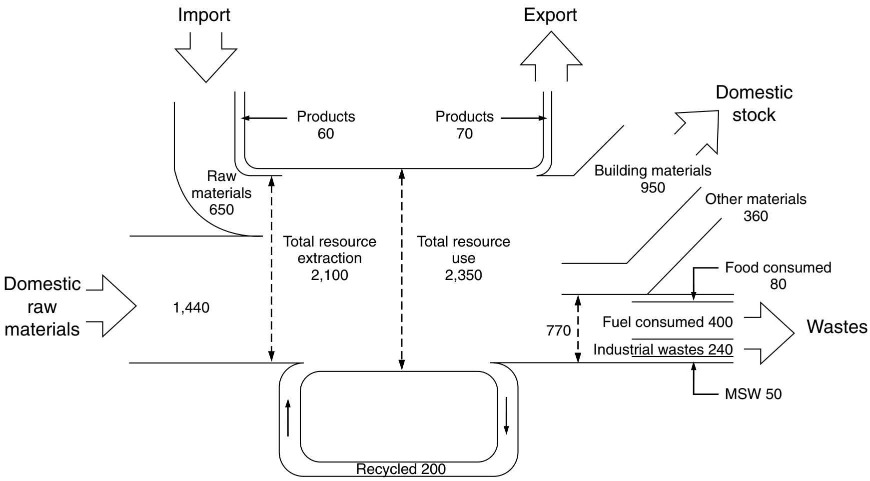

FIGURE 2 Japan's annual material balance (FY 1990). All values in million metric tons (1 metric ton = 1,000 kilograms). SOURCE: Official Japanese statistics.

and dissipative uses of materials and energy (Figure 3) (Gotoh, 1974). To move to a sustainable society, overall environmental efficiency will have to be improved. To approach complete closure of materials cycles in society, present industrial ecosystems, which are readily identifiable in interrelated production processes, interacting industrial sectors, and interacting production, consumption, and waste-management systems need to be assessed to identify opportunities for enhancing and continually improving environmental efficiencies.

THE POTENTIAL AND LIMITS OF USING LIFE CYCLE APPROACHES

Industrial practices to minimize total environmental load and improve the environmental efficiency of industrial ecosystems occur in three areas: product design and makeup, process design and operation, and business management strategy. A variety of life cycle analyses and clean production (or environmental management) systems are used for product and process improvement strategies; environmental auditing and environmental performance evaluation are used to manage business strategies. In these endeavors, environmental life cycle methodologies play a key role.

Nearly a dozen life cycle schemes and procedures have been proposed to date. Broadly, they may be classified into two approaches. The first, based on practical engineering experiences in industry, is known by such names as design for environment (Allenby, 1994), design for recyclability (Henstock, 1988), or simply ecodesign in different countries of Europe. This approach involves quali-

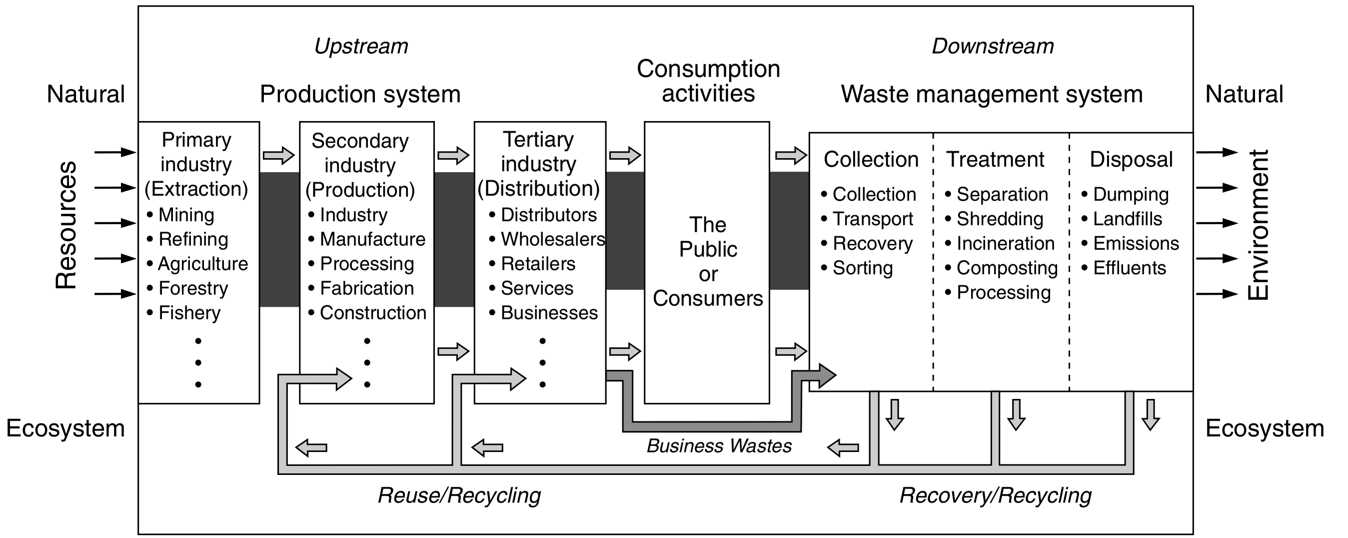

FIGURE 3 Material flows in the human ecosystem or society. Wastes from the productive industry system are not shown. SOURCE: Gotoh, 1974.

TABLE 1 List of Evaluation Items and Criteria Used in Product Assessment

Factor	Item to Be Evaluated	Example of Criteria Used
Product Weight	Weight of materials and parts in use	Relative weight reduction achieved
Recyclability	Substitutable materials or parts	Materials or parts that can be substituted for others
Crushability	Ease of crushing or shredding	Crushability or shredability of product
Disintegratability	Ease of fabricating or dismantling	Designed for disassembling?
Separability	Coding of plastic materials and	Coding of plastics given and easily seen?
Transportability	Ease of handling, collection, and transportation	Designed for easy handling and transportation?
Safety and Health	Toxicity of materials used and hazard	Designed for safety after retirement?
Packaging	Weight and size of packaging	Packaging materials minimized?
Information	Disposal and recycling information	Information on disposability and recyclability given properly?

tative evaluations of the environmental impacts of a product by using checklists, scoring sheets, and reviews of flow charts for relevant processes. In Japan, this is generally known as product assessment. For example, manufacturers of electric appliances for the home are required, during early stages of planning and design, to perform a preliminary product assessment on materials use, product structure design, and recyclability when the product is retired, in accordance with MITI's guidelines (MITI Order No. 55, October 25, 1991). This assessment is stipulated in the Japanese recycling law regarding the designated "products of the first kind." Table 1 presents a simplified standard checklist for this purpose. Manufacturers will usually develop far more detailed evaluative checklists and scoring sheets. Several products that have been improved by these assessments are already on the market from leading companies such as Hitachi and Matsushita.

The second approach, based on detailed material and energy balances or inventories taken at different stages of product life cycle, requires a quantitative analysis and evaluation of a product and its associated processes, or the product system. The terms life cycle inventory, life cycle analysis, and product life cycle assessment (PLCA) have been recently coined to denote this approach. The life cycle methodology is a powerful tool that can help manufacturers analyze and improve their products and directly associated processes. It is also intended to assist public policy makers in formulating environmental legislation and to enable consumers to make better-informed purchases.

The type of information needed differs depending on whether it is used for internal (within company) or external (public) purposes. Internal decision-makers (such as product designers and engineers) require specific and technical information to choose environmentally improved materials, improve energy use, and select alternative process designs and operations. Some information may also be used by a company's top management in research and development decisions about new products or services and in gauging future business opportunities. Less-specific information may be used for public policy purposes, but for internal purposes the information has to be scientifically proven and comprehensive yet clear-cut and easily understandable.

A general procedural scheme for conducting a rigorous PLCA is shown in Figure 4 (Gotoh, 1993). It is similar to the technical framework proposed by the Society of Environmental Toxicology and Chemistry (1991, 1993). The scheme includes clear goal definition and scoping at the outset but emphasizes the dynamic and reiterative nature of life cycle assessment practices for continuous improvement of environmental attributes of products.

Conducting a rigorous PLCA using this comprehensive scheme is a very detailed, time-consuming, and costly exercise. In principle, obtaining useful information for decision making is relatively uncomplicated if the boundary of the study is clearly defined, the methodology is strictly applied, and reliable, high-quality data are available. However, these are fairly large provisions that are usually not realized in many practices.

In 1992, the Federation of Japan Consumers Cooperatives conducted an extensive PLCA of the packaging materials they use. The study involved doing a life cycle inventory (step 2) and impact analysis (step 3) for four beverage containers currently in use by the cooperatives. The study identified and calculated environmental loads associated with different life stages of the containers, in-

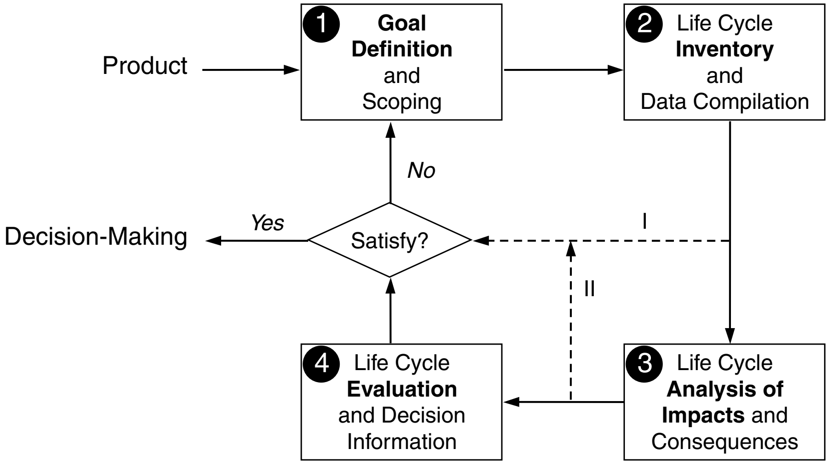

FIGURE 4 Basic procedural scheme for conducting a product life cycle assessment. SOURCE: Gotoh, 1993.

cluding manufacturing. The information, however, has not been very useful for determining which container is environmentally superior. This is because the impact analysis (step 3) and integrated evaluation (step 4) involve value judgments that are necessarily subjective. One can hardly compare heavy energy use with less water effluent and reach one conclusion. It is like trying to compare apples and oranges. To overcome this kind of difficulty, SETAC currently recommends including a peer-review process to enhance the credibility as well as the scientific and technical quality of assessments (SETAC, 1993).

The International Standardization Organization has serious efforts under way to develop an internationally acceptable and standardized methodology of rigorous PLCAs. However, this venture clearly bucks current trends that allow manufacturers maximum creativity and ingenuity and favor industry's diversified, voluntary life cycle practices as a way to improve the environmental attributes of products.

Since 1985, well over 100 PLCAs have been carried out in Europe, North America, and Japan, most of them concerned with packaging materials, especially food and drink containers. This means that the application of the present rigorous methodology of PLCA has been limited to rather simple products of simple design. For durable products of sophisticated design such as a television set or an automobile, the methodology does not appear to be applicable because of the large amount of data required for every component involved, the extensive analysis required, and the many assumptions that have to be made. In addition, different results are possible from using the same methodology to compare two similar products. For example, two comparable PLCA studies applied to the same packaging material but that assumed different end-of-life disposal methods yielded results differing by several hundred percent (Pedersen, 1993).

Recently, however, a new approach for evaluating environmental loading of complicated products has been emerging. Data from output tables are used for inventory analysis, (e.g., for an average automobile), and total life cycle environmental loading—materials and energy used in different but interrelated industrial sectors and consumption—is estimated and evaluated. Kondo et al. (1993) calculated total life cycle carbon dioxide emissions for an average-sized Japanese passenger car by analyzing 408 interacting industrial sectors of the Japanese 1985 input-output table. The approach still needs to be refined, but it is a promising tool for assessing the environmental loading of durable goods.

RECYCLABILITY: A MEASURE FOR SUCCESS OF CORPORATE ENVIRONMENTAL STEWARDSHIP?

The human ecosystem, defined in Figure 3, constantly intersects with local, regional, and global natural ecosystems through interchange of materials and energy as natural resources and wastes. It is a complex and dynamic system with a large number of subsystems identifiable within numerous industrial ecosystems.

Natural biological ecosystems are complex. One of their important features is that abiotics, such as nutrients, circulate dynamically and are constantly recycled through producer, consumer, and decomposer organisms. The metabolic activities of ecosystems run on sun energy. In a sound natural ecosystem, therefore, everything has a use and there are no waste materials.

Closing the material circle as a whole is necessary if the model of natural ecology is to be used to construct a mature sustainable industrial ecology and to transform the present throw-away society into a sustainable recycle society. Hence, from an industrial ecology perspective, recycling is important for improving the overall environmental performance of society. Strategically, to minimize loss, recycling should be promoted first in interrelated industrial processes (in-plant recycling) and among different industrial sectors (interindustry recycling) and then among interacting production, consumption, and waste management systems (postconsumer recycling). For nearly 2 decades, waste-exchange programs have been used in Japan to foster interindustry recycling in almost all prefectural governments, where the governor is responsible for formulating a local industrial waste-management plan.

Recycling, by definition, is an economically viable activity that recovers, reprocesses, and reuses materials that are otherwise deemed waste. In principle, three types of recycling, encompassing both closed- and open-loop recycling, are possible (Figure 5) (Gotoh, 1976). In open-loop recycling, a waste product is reclaimed, reprocessed, or reused in a different product. Recycling priorities

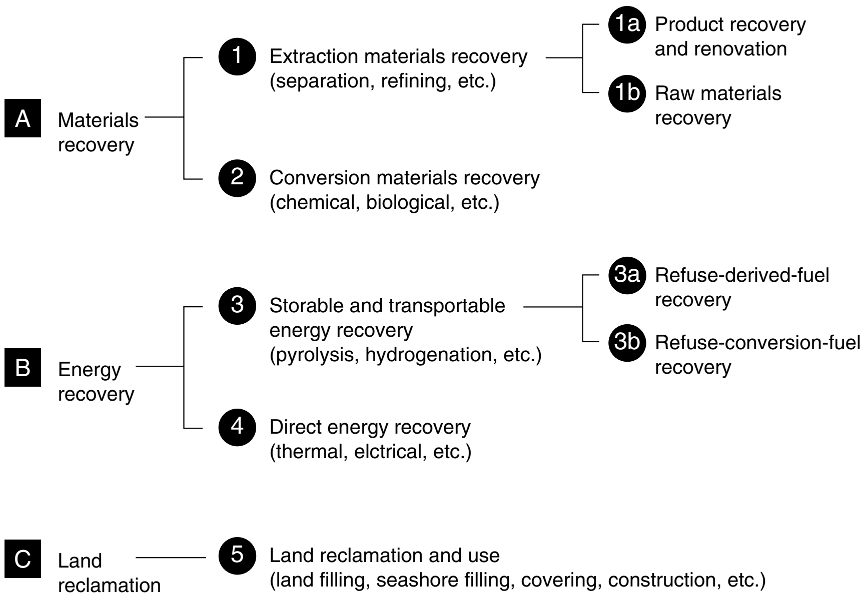

FIGURE 5 Types of resource recovery and recycling. SOURCE: Gotoh, 1976.

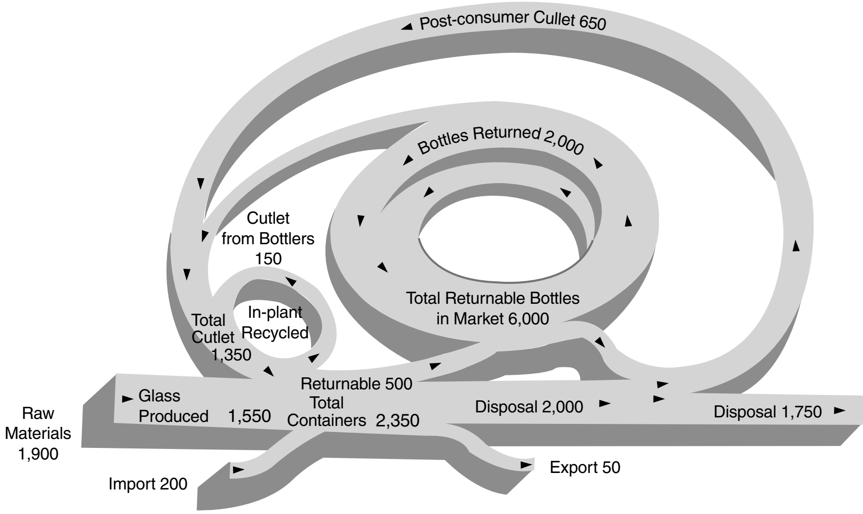

FIGURE 6 Flows and balance of glass containers in Japan. All numbers in 1,000s of tons per year. SOURCE: Gotoh, 1992.

should be set strategically for cascading use, from product recovery and renovation and raw materials recovery, to harnessing embedded energy from refuse, to disposal and land reclamation. For example, if recovered waste paper is of low quality and other technical and economic factors prevent reprocessing and reuse, the paper should first be recycled into the next lower grade paper product, then into a nonpaper product such as wallboard or compost, then into refuse-derived fuel to be eventually burned to recover energy in the form of steam or electricity.

Several commodity-specific recycling rates and schedules for meeting the goals are provided by the Japanese government to gauge environmental progress in industry and to set goals for other industrial efforts to improve the environmental efficiency. Figure 6 shows the flow and balance of glass containers and cullet in 1992. The target cullet reuse rate of 55 percent by the end of FY 1995 was met and exceeded in 1992, when the reuse rate was found to be about 56 percent. Numerous other variables to track recycling progress could be defined such as cullet use rate excluding in-plant and bottlers' cullet, return rate of returnable bottles, returnable bottle use rate, and total glass recycling rate. These may be useful for gauging industry's environmental progress.

SUMMARY

The Japanese experience suggests the following:

- To improve the environmental efficiency of industrial ecosystems, close and well-coordinated collaboration between industry and government is indispensable.

- Several methods are available to industry for improving the environmental attributes of products. They fall into two categories: the first, represented by such approaches as design for environment, is based on checklists and scoring sheets; the second, represented by life cycle analysis, requires detailed inventory analyses. From a practical viewpoint, life cycle analysis has been limited to products of simple design because of the difficulty of performing detailed analysis on and collecting large amounts of data about more complex products.
- A more efficient industrial ecology in the context of Seaborg's recycle society is necessary for a global sustainable society, and recycling rates can be a measure of environmental progress.

REFERENCES

Allenby, B. R. 1994. Integrating environment and technology: Design for environment. Pp. 137–148 in The Greening of Industrial Ecosystems, B. R. Allenby and D. J. Richards, eds. Washington, D.C.: National Academy Press.

Gotoh, S. 1974. Proper waste disposal and recycling systems [in Japanese]. Sangyo Kogai 10:1705–1717.

Gotoh, S. 1976. Improving waste management systems [in Japanese]. Toshi Kankyo Kogaku 8(2):3–17.

Gotoh, S. 1992. Japan's approach to a resource recycle economic society. Pp. 443–449 in Waste Management International, Volume 1, K.J. Thome-Kozemiensky, ed. Berlin: EF-VERLAG.

Gotoh, S. 1993. A comprehensive methodological scheme for product life-cycle assessment (PLCA). Presented at the Symposium K (Ecomaterials) of IUMRS-ICAM-93, The International Union of Materials Research Societies - The International Conference on Advanced Materials, Tokyo, August 1993.

Henstock, M. E. 1988. Design for Recyclability. London: Institute of Metals.

Japan Environment Agency. 1990. Annual White Paper on the Environment. Tokyo: Japan Environment Agency.

Japan Environment Agency. 1991. Towards a Recycle Society in the 21st Century [in Japanese]. Tokyo: Chuo Hoki Shuppan.

Japan Environment Agency. 1993. Action Program for Environmentally Conscious Cooperates. Tokyo: Japan Environment Agency.

Keidanren. 1990a. View on Global Environmental Issues. Tokyo: Keidanren.

Keidanren. 1990b. Agenda for Improvement of Waste Management. Tokyo: Keidanren.

Keidanren. 1991. Global Environmental Charter. Tokyo: Keidanren.

Kondo, Y., Y. Moriguchi, and H. Shimizu. 1993. Analysis of carbon dioxide emission by material production and its application to automotive production. Presented at the Symposium K (Ecomaterials) of IUMRS-ICAM-93, Tokyo, August 1993.

Ministry of International Trade and Industry. 1992. The Voluntary Plan. Tokyo. Ministry of International Trade and Industry.

Pedersen, B., ed. 1993. Environmental Assessment of Products: A Text-Book on Life Cycle Assessment, 2nd edition. Helsinki: University-Enterprise Training Partnership in Environmental Engineering Education.

Seaborg, G. T. 1974. The recycle society of tomorrow. The Futurist (June):108–115.

Society of Environmental Toxicology and Chemistry. 1991. A Technical Framework for Life-Cycle Assessment. 1990 Workshop Report. Pensacola, Fla.: Society of Environmental Toxicology and Chemistry.

Society of Environmental Toxicology and Chemistry. 1993. Guidelines for Life-Cycle Assessment: A 'Code of Practice' 1993 Workshop Report. Pensacola, Fla.: Society of Environmental Toxicology and Chemistry.

Tolba, M. K., and O. A. El-Kholy, eds. 1992. The World Environment 1972-1992: Two Decades of Challenge. London: Chapman & Hall.

World Commission on Environment and Development. 1987. Our Common Future. Oxford: Oxford University Press.

Yumoto, N. 1994. Japan's Recycling Law and the "Ecofactory". Pp. 37–39, Industrial Ecology: U.S.-Japan Perspectives, D. J. Richards, and A. B. Fullerton, eds. Washington, D.C.: National Academy Press.

APPENDIX 1

KEIDANREN GLOBAL ENVIRONMENT CHARTER

Introduction

Japan has been actively striving to protect the environment, promote health and safety, and use energy and resources more efficiently ever since pollution became a problem in the high-growth 1960s and especially since the two oil crises of the 1970s, and now has some of the most advanced technologies and systems in the world to reduce industrial pollution, enhance safety and hygiene, and conserve energy and other resources.

Yet today's environmental problems are too critical to be dealt with solely through measures to prevent industrial pollution. If we are to minimize the load on the environment from, for example, waste disposal and water pollution generated in cities, society itself must be fundamentally changed. We must radically revise various social and economic systems, such as the layout of cities and the arrangement of transport networks, and we must also upgrade social infrastructure and, indeed, raise the consciousness of citizenry.

On the international agenda are such world-scale problems as global warming, the depletion of tropical rain forests, desertification, acid rain, and pollution of the oceans. The international community's response to the problem of global warming in particular will be having profound effects on our ways of life and business. Naturally, there must be overall measures taken, but technological breakthrough will also be necessary. The problems are such that no country alone can come up with all the answers.

The task before us is not merely one of rethinking the problems cause by the pursuit of affluence in a culture that encourages mass consumption; we must also come to grips with the global problems of poverty and population increase, aiming to hand over to future generations a healthy environment that allows sustainable development on a global scale. The governments, companies, and people of each nation must become more aware of their roles in this endeavor. People throughout the world must join hands to create new social and economic systems that allow the advancement of the welfare of all human beings and the conservation of the whole world's environment.

Japan must not rest content with its good record in pollution control thus far. The business world, academic circles, and government must pool their resources to create innovative technologies for preserving the environment, conserving energy, and cutting back on resource consumption. While drawing on the Japanese experience in reconciling economic development with environmental protection, we must actively participate in international environmental undertakings. Concerning such problems as global warming, we should support the efforts on more scientific research into their causes and effects and also begin work immediately on the feasible countermeasures.

By showing that it takes environmental problems seriously, the business world can gain the trust and sympathy of the public. This will foster a mutually beneficial relationship between producers and consumers, thereby encouraging the healthy development of the economy. With the above situation in mind, Keidanren offers the guidelines outlined below to its members. It is to be hoped that each member, always consulting with and seeking the understanding and cooperation of consumers, government officials, and others, will conduct its business in conformity with these guidelines.

Basic Philosophy

A company's existence is closely bound up with the global environment as well as with the community it is based in. In carrying on its activities, each company must maintain respect for human dignity, and strive toward a future society where the global environment is protected.

We must aim to construct a society whose members cooperate together on environmental problems, a society where sustainable development on a global scale is possible, where companies enjoy a relationship of mutual trust with local citizens and consumers, and where they vigorously and freely develop their operations while preserving the environment. Each company must aim at being a good global corporate citizen, recognizing that grappling with environmental problems is essential to its own existence and its activities.

Guidelines for Corporate Action

Companies must carry on their business activities to contribute to the establishment of a new economic social system for realizing an environmentally protective society leading to the sustainable development.

General Management Policies

Companies should always consult the guidelines below in carrying on their activities. They must work to (1) protect the global environment and improve the local living environment, (2) take care to protect ecosystems and conserve resources, (3) ensure the environmental soundness of products and (4) protect the health and safety of employees and citizens.

Corporate Organization

1. Companies shall establish an internal system to handle environmental issues by appointing an executive and creating an organization in charge or environmental problems.
2. Environmental regulations shall be established for company activities, and these shall be observed. Such internal regulations shall include goals for reducing the load on the environment. An internal inspection to determine how well the environmental regulations are being adhered to shall be carried out at least once a year.

Concern for the Environment

1. All company activities, beginning with the siting of production facilities, shall be scientifically evaluated for their impact on the environment, and any necessary countermeasures shall be implemented.
2. Care shall be taken in the research, design, and development stages of making a product to lessen the possible burden on the environment at each level of its production, distribution, appropriate use, and disposal.
3. Companies shall strictly observe all national and local laws and regulations for environmental protection, and where necessary they shall set additional standards of their own.
4. When procuring materials, including materials for production, companies shall endeavor to purchase those that are superior from such viewpoints as conserving resources, preserving the environment, and enhancing recycling.
5. Companies shall employ technologies that allow efficient use of energy and preservation of the environment in their production and other activities. Companies shall endeavor to use resources efficiently and reduce waste products through recycling, and shall appropriately deal with pollutants and waste products.

Technology Development

In order to help solve global environmental problems, companies shall endeavor to develop and supply innovative technologies, products and services that allow conservation of energy and other resources together with preservation of the environment.

Technology Transfers

1. Companies shall seek appropriate means for the domestic and overseas transfer of their technologies, know-how and expertise for dealing with environmental problems and conserving energy and other resources.
2. In participating in official development assistance projects, companies shall carefully consider environmental and antipollution measures.

Emergency Measures

1. If environmental problems ever occur as a result of an accident in the course of company activities or deficiency in a product, companies shall adequately explain the situation to all concerned parties and take appropriate measures, using their technologies and human and other resources, to minimize the impact on the environment.
2. Even when a major disaster or environmental accident occurs outside of a company's responsibility, it shall still actively provide technological and other appropriate assistance.

Public Relations and Education

1. Companies shall actively publicize information and carry out educational activities concerning their measures for protecting the environment, maintaining ecosystems, and ensuring health and safety in their activities.
2. The employees shall be educated to understand the importance of daily close management to ensure the prevention of pollution and the conservation of energy and other resources.
3. Companies shall provide users with information on the appropriate use and disposal, including recycling, of their products.

Community Relations

1. As community members, companies shall actively participate in activities to preserve the community environment and support employees who engage in such activities on their own initiative.
2. Companies shall promote dialogue with people in all segments of society over operational issues and problems seeking to achieve mutual understanding and strengthen cooperative relations.

Overseas Operations

Companies developing operations overseas shall observe the Ten-Point Environmental Guidelines for the Japanese Enterprises Operating Abroad in Keidanren's Basic Views of the Global Environmental Problems (April 1990).[1]

Contribution to Public Policies

1. Companies shall work to provide information gained from their experiences to administrative authorities, international organizations, and other bodies formulating environmental policy, as well as participate in dialogue with such bodies, in order that more rational and effective policies can be formulated.
2. Companies shall draw on their experience to propose rational systems to administrative authorities and international organizations concerning formulation of environmental policies and to offer sensible advice to consumers of lifestyles.

Response to Global Problems

1. Companies shall cooperate in scientific research on the causes and effects of such problems as global warming and they shall also cooperate in the economic analysis of possible countermeasures.
2. Companies shall actively work to implement effective and rational measures to conserve energy and other resources even when such environmental problems have not been fully elucidated by science.
3. Companies shall play an active role when the private sector's help is sought to implement international environmental measures, including work to solve the problems of poverty and overpopulation in developing countries.

NOTE

1. Ten-Point Environmental Guidelines for the Japanese Enterprises Operating Abroad
    1. Establish a constructive attitude toward environmental protection and try to raise complete awareness of the issues among those concerned.
    2. Make environmental protection a priority at overseas sites and, as a minimum requirement, abide by the environmental standards of the host country. Apply Japanese standards concerning the management of harmful substances.
    3. Conduct a full environmental assessment before starting overseas business operations. After the start of activities, try to collect data, and, if necessary, conduct an assessment.
    4. Confer fully with the parties concerned at the operational site and cooperate with them in the transfer and local application of environment-related Japanese technologies and know-how.
    5. Establish an environmental management system, including the appointment of staff responsible for environmental control. Also, try to improve qualifications for the necessary personnel.
    6. Provide the local community with information on environmental measures on a regular basis.

7. Be sure that when environment-related issues arise, efforts are made to prevent them from developing into social and cultural frictions. Deal with them through scientific and rational discussions.
8. Cooperate in the promotion of the host country's scientific and rational environmental measures.
9. Actively publicize, both at home and abroad, the activities of overseas businesses that reflect our activities on the environmental consideration.
10. Ensure that the home offices of the corporations operating overseas understand the importance of the measures for dealing with environmental issues, as they effect their overseas affiliates. The head office must try to establish a support system that can, for instance, send specialists abroad whenever the need arises.

APPENDIX 2

EXCERPTS FROM JAPAN'S BASIC ENVIRONMENT LAW (1993)

ARTICLE 2

(Terminology)

1. For the purpose of this law, "environmental load" means any adverse effects on the environment generated by human activities which may cause interference with environmental conservation.

2-3. Omitted

ARTICLE 4

(Creation of a Society Ensuring Sustainable Development with Reduced Environmental Load)

Environmental conservation shall be promoted so that a society can be formulated where the healthy and productive environment is conserved and sustainable development is ensured by fostering sound economic development with reduced environmental load, through practices on environmental conservation such as reducing as much as possible the environmental load generated by socio-economic and other activities, which are voluntarily and positively pursued by all the people sharing fair burden; and so that interference with environmental conservation can be anticipatorily prevented through enhancing scientific knowledge.

ARTICLE 8

(Responsibility of Corporations)

1. Omitted.
2. In manufacturing, processing or selling products, or engaging in other

business activities, corporations are responsible for taking necessary measures for ensuring proper disposal of the wastes generated from products and other goods related to their activities, so as to prevent interference with environmental conservation, pursuant to the basic principles.

3. Besides the responsibilities prescribed in the preceding two paragraphs, in manufacturing, processing or selling products, or engaging in other business activities, corporations are responsible for making efforts to reduce the environmental loads resulting from the use or disposal of the products and other goods related to their activities; and for making efforts to use recyclable resources and other materials and utilities which contribute to reducing the environmental loads in their activities, so as to prevent interference with environmental conservation, pursuant to the basic principles.
4. Omitted.

ARTICLE 22

(Economic Measures to Prevent Interference with Environmental Conservation)

Omitted

ARTICLE 24

(Promotion of Use of Products Assisting to Reduction of Environmental Load)

1. The State shall take necessary measures such as providing corporations with technical assistance so that, in manufacturing, processing or selling products, or engaging in other business activities, they can appropriately consider the reduction of the environmental load associated with products and other goods, by voluntarily assessing in advance the environmental load generated by the use or disposal of the products and other goods.
2. The State shall take necessary measures to encourage use of recyclable resources and other materials, products and services which contribute to the reduction of environmental load.

Biographical Data

BRADEN R. ALLENBY is currently vice president for environment, health, and safety at AT&T. He is a member of the Virginia Bar and has worked as an attorney for the Civil Aeronautics Board and the Federal Communications Commission, as well as been a strategic consultant on economic and technical telecommunications issues. Allenby joined AT&T in 1983 as a telecommunications regulatory attorney and was an environmental attorney and senior environmental attorney at AT&T from 1984 to 1993. During 1992, he was the J. Herbert Holloman Fellow at the National Academy of Engineering in Washington, D.C. In 1994, he was appointed vice president for technology and environment with AT&T's Engineering Research Center and was seconded from AT&T in 1995 to Lawrence Berkeley National Laboratories, where he directed the lab's energy and environmental systems until he assumed his current position at AT&T. Renowned for his pioneering work on industrial ecology, Allenby is the co-author of the first textbook on industrial ecology, published in 1995, and he conducts seminars and workshops on the subject. Allenby is a fellow of the Royal Society for the Arts, Manufactures & Commerce. He graduated cum laude from Yale University in 1972, received a J.D. from the University of Virginia Law School in 1978, and earned an M.A. in economics from the University of Virginia in 1979. He received an M.A. in environmental sciences from Rutgers University in 1989 and a Ph.D. in environmental sciences from Rutgers in 1992.

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DAVID R. COPE is executive director of the U.K. Center for Economic and Environmental Development in Cambridge, England. The center is a charitable foundation set up in 1984 to conduct research on and to promote adoption of policies that advance economic growth while ensuring a high quality environment. The center has its own programs and also works in collaboration with international, national, and local governments, foundations, voluntary groups, private enterprises, and trade associations. Cope was formerly the environmental team leader of the International Energy Agency (IEA) Coal Unit. Prior to his work at the IEA, he was an associate professor of energy and environment studies at the University of Nottingham, England. He has been an adviser to the U.K. government (on clean technologies and climate-change policy), an independent member of the committee set up to evaluate the implications of the Chernobyl incident for the United Kingdom, and a member of the Central Electricity Generating Board's environmental advisory panel. Cope has a B.A. in economics from Cambridge University and an M.A. in economics from the London School of Economics.

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