

# Green Product Design

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**Thomas E. Graedel**

**Paul Reaves Comrie**

**Janine C. Sekutowski**

Most of the environmental impacts of a product are determined by the product designer, who is a major determinant in AT&T's manufacture of *green*—that is, environmentally responsible—products. This paper presents some elements of “green design,” an activity termed *design for environment* (DFE). DFE incorporates two types of activities: generic and specific. Generic activities are reliable general guidelines for environmentally preferable approaches, such as the minimization of energy use; specific activities are related to individual products, such as the choice of particular materials. AT&T has developed and applied a DFE evaluation methodology to its telecommunications products. These products generally rate reasonably well from a DFE standpoint, but assessments show a number of areas in which improvements can be made. These can be implemented not only by product designers, but also by manufacturing engineers and supply line managers.

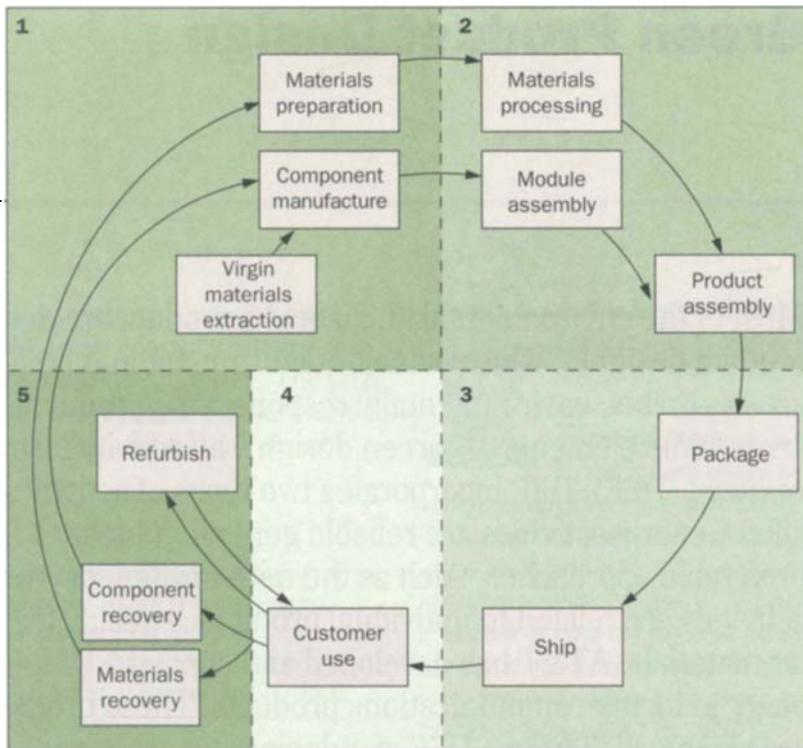
## Introduction

*Design for environment* (DFE) is a concept concerned with reducing the environmental impact of a product throughout its entire life cycle, from design through manufacturing, packaging, distribution, installation, use, and end of life.<sup>1</sup> It is a proactive approach to environmental protection that addresses life-cycle environmental concerns in the product design stage. Decisions made during that stage profoundly influence the entire life cycle of the product and determine 80 to 90 percent of its total life-cycle costs. Integrating environmental concerns into the design stage mitigates environmental problems later in the product's life cycle, resulting in an overall reduction in associated lifetime financial liabilities, such as manufacturing process waste disposal costs and product disassembly and disposition costs.

The electronic product development process encompasses physical design, electrical design, manufacturing engineering, and product packaging and documentation. Physical design is the design of the product housing or enclosure and of the way in which

electronic modules, connectors, fans, and the like are assembled within it. Electrical design involves the operational constituents of the product, including the printed wiring board (PWB) and components selected to populate the PWB. Manufacturing engineering is the implementation of the manufacturing process. Product delivery includes the preparation of the product itself for distribution and sale, and the preparation of the associated documentation, such as installation instructions or user manuals.

Designers have traditionally considered only the cost and final performance of their designs, and perhaps the degree to which they are readily manufacturable. The new concern with the environmental approach to the entire product life cycle requires that all life stages be addressed in a structured way. Figure 1 shows the five life-cycle stages in a typical product manufactured by AT&T. Stage 1, premanufacture, is performed by AT&T suppliers, generally drawing on virgin resources and producing materials and components. Stage 2 is the



**Figure 1. Activities in the five life-cycle stages (shown as numbers) of a product manufactured for customer use. In an environmentally responsible product, the environmental impacts are minimized in each stage, not only in Stage 2. The long-term goal is to reintroduce all material in discarded products into the resource streams that flow into new products.**

manufacturing operation, directly under AT&T's control, as is Stage 3, packaging and transport. Stage 4, the customer use stage, is influenced by both the user and the degree of continuing manufacturer interaction. (A leased product under maintenance contract maximizes the interaction, for example.) In Stage 5, a product is no longer satisfactory because of obsolescence, component degradation, or changed business or personal decisions. At this point, it is refurbished or discarded. This last stage, which in many industries is performed by other than the manufacturer, will increasingly become a general function of AT&T and others, because lease and take-back activities for products of all kinds are expected to become common. Stage 2 and, perhaps, Stage 3 have been customarily regarded as those in which industry's environmental responsibility lies. The evolving vision both inside and outside corporations, however, is that an environmentally responsible product minimizes its impact on the external environment at all five stages of its life—that is, from cradle to reincarnation (not cradle to grave, because the materials and components of a well-designed product are recycled, and there is no grave).

**Panel 1. Abbreviations, Acronyms, and Terms**

- DFE—design for environment
- EPA—Environmental Protection Agency
- HASL—hot air solder-leveled
- ISO—International Organization for Standardization
- PWB—printed wiring board
- UL—Underwriters Laboratories

**Elements of Green Design in Electronics**

The perspective described above provides a framework for more specific recommendations. Some important guidelines for the greening of electronic products include materials selection, enclosure or exterior housing, subassemblies, circuit pack design, product delivery, and design for recycling, as described in the sections that follow.

**Materials Selection.** An initial consideration of designers should be to minimize the number of different materials used in a product. For example, designers should use the same type and grade of plastic for as many plastic parts as possible, to avoid the need for extensive separation of product components at the end of product life.

Wherever it is possible, designers should specify recycled, rather than virgin, material. If recycled material cannot meet materials specification requirements, designers should consider using blends of virgin and recycled materials. If no recycled material is suitable, it should at

**Table I. Chemicals Identified in the U.S. EPA's Industrial Toxics Project**

Benzene	Cadmium and compounds
Carbon tetrachloride	Chloroform
Chromium and compounds	Cyanides
Dichloromethane	Lead and compounds
Mercury and compounds	Methyl ethyl ketone
Methyl isobutyl ketone	Nickel and compounds
Tetrachloroethylene	Toluene
Trichloroethane	Trichloroethylene
Xylenes	

least be possible to use a material that will be recyclable at the end of product life.

Another consideration in choosing materials is their potential for toxicity. Other things being comparable for a specific application, designers should select a material that has no significant toxic properties. Government environmental agencies have defined the levels of toxicity for many materials. Table I lists the 17 chemicals or chemical groups targeted for reductions in the Industrial Toxics Project of the U.S. Environmental Protection Agency (EPA), a voluntary effort by industrial corporations to reduce emissions of targeted chemicals. Both product chemicals and process chemicals are included in the list. Cadmium, chromium, lead, mercury, nickel, and their compounds are sometimes used in electronic components. Most of the remaining materials are process chemicals that may be used as either solvents or cleaners in circuit pack processing. Designers should consider two facets of materials choices involving toxic materials: the potential for materials substitution and the potential for process changes.

Many materials shown in Table I are also restricted substances in the European Union<sup>2</sup> and should be avoided on that account. Additional materials on the European Union list include polybrominated biphenyls and biphenyl ethers, which are flame-retardant additives. These materials are deemed hazardous by various regulatory agencies in Europe and have been put on a phase-out schedule.

All plastic parts should be marked with International Organization for Standardization (ISO) identifying

marks, size, geometry, and function permitting.<sup>3</sup> AT&T has instituted such a marking system for plastic parts to help identify and sort materials for recycling.

**Enclosure or Exterior Housing.** Once the material for the exterior housing has been selected, it is important to consider how the product is put together. It should be easy to assemble and disassemble. Easy disassembly helps when it is time to separate materials for recycling. It also permits efficient repair and refurbishment. Extending the lifetime of the product minimizes its environmental impact; as long as the product is in use, materials are not consumed to manufacture a replacement.

The appearance requirements of the exterior housing also have an environmental component. Any surface treatment required should be compatible with the underlying material. For example, a plastic part with metal plating cannot be recycled, so plating of plastics should be avoided unless it is functionally required. The same is true for painting plastic parts, unless the paint is compatible with the plastic and can be reground with it for subsequent reuse with no degradation of material properties. Labels, such as Underwriters Laboratories (UL) or safety labels, should be molded into, rather than glued on, parts, because labels that are not compatible must be removed before the material is recycled. If incompatible labels are ground up with plastic parts, they contaminate the plastic regrind and degrade its material properties.

**Subassemblies.** Subassemblies should be designed with modularity in mind. The subassembly should be easy to connect and disconnect to the product, making repair of the entire product modular. Ideally, the subassembly should also be designed for easy repair, by placing components that are prone to fail in easily accessible locations on the module.

For the long term, the entire product should be designed with the intent of maximizing its life. Designing modules that are easily replaced with the next generation of technology makes it more feasible to upgrade the product, rather than replace it entirely.

**Circuit Pack Design.** Although at this time no suitable lead-free alternatives to tin-lead soldered interconnections exist, except in certain niche applications, a designer can still minimize the lead content of a circuit pack. Surface-mount technology requires less solder

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than through-hole technology does. New interconnection technologies, such as microball grid array and direct chip attachment, also require less total solder on a circuit pack. Environmental benefits increase with the use of advanced interconnection technologies.

The surface finish of the PWB and component wire leads can also contribute to the total lead content of a circuit pack. Designers can specify the use of organic solderability preservative finishes, such as imidazole, to replace the tin-lead of the hot air solder-leveled (HASL) surface finish of a PWB. In the case of components from suppliers, tin and nickel/palladium component wire surface finishes can be used in place of tin-lead finishes. Changing from through-hole to surface-mount technology, when possible, eliminates wire finish problems altogether.

Placement of components on PWBs must be considered from an end-of-life standpoint. If any components contain hazardous materials, as was the case with the once-common but now obsolete mercury relays, they must be removed from scrapped circuit packs before the packs can be processed for precious metal recovery. To the extent that hazardous material use is unavoidable, these components should be positioned in an area on the board where they can be easily accessed and removed. Typically, it takes more effort to remove a component located near the center of the board than one located along the board perimeter, particularly if the board is densely populated.

To minimize the refining fee charged by smelters, which is based on the total weight of scrapped circuit packs, heavy circuit components should be placed where they can be easily stripped away. Furthermore, because iron and copper-rich components are eminently recyclable in their own right, it makes sense to collect them as a separate category of recyclable scrap. Typically, the heavy circuit components are iron and/or copper-rich through-hole-mounted components, such as power transformers, induction coils, and heat sinks. To make their removal easier, these components should be positioned near the edge of the PWB.

The electrical design of a circuit pack should be energy efficient. Personal computers, for example, are being designed to switch automatically to a low energy state when they are left idle. This is part of the U.S. EPA's Energy Star Computers Program. A personal computer

and its monitor built with today's technology draw about 150W of power. The Energy Star computers are designed to enter a low power state, in which each component—the computer and the monitor—draws 30W or less. Similar requirements apply to computer printers. A manufacturer meeting these requirements is eligible to display the Energy Star logo when advertising its products. The majority of recent computers meet the standard, which is being extended to other electromechanical and electronic products.

**Product Delivery.** Most customers would rather not have to deal with product packaging. As engineers develop packaging systems that are minimal or easy to reuse or recycle, the product within becomes more attractive to the customer. In addition, many customers and countries now require manufacturers to take back the packaging material from their products. This is another incentive to minimize the environmental impact of product packaging. The packaging designer should generally adopt the following packaging guidelines (listed in order of environmental preference, as suggested by the U.S. Council of Northeast Governors):

- No packaging,
- Minimal packaging,
- Consumable, returnable, or refillable/reusable packaging, and
- Recyclable packaging.

In addition, packaging designers should specify the minimum number of different materials, and recycling instructions should be prominently displayed. Product documentation, such as user manuals and installation instructions, should be printed on recycled paper.

**Design for Recycling.** An engineer's instinct is to design products that will work forever. This approach, however, is inappropriate in a time when many products become totally obsolete in less than five years' time. Modern products must be built to last, but only until it is time to take them apart for rebuilding or for reuse of materials.

This paper has already described several attributes of design for recycling, including:

- Minimizing plating and painting,
- Choosing recyclable materials,
- Identifying all plastics, and
- Using a modular design approach.

This list should also include guidance on ease of assembly and disassembly. Chemical bonds and welds

Life stage	Environmental concern				
	Materials choice	Energy use	Solid residues	Liquid residues	Gaseous residues
Premanufacture	1,1	1,2	1,3	1,4	1,5
Product manufacture	2,1	2,2	2,3	2,4	2,5
Product delivery	3,1	3,2	3,3	3,4	3,5
Product use	4,1	4,2	4,3	4,4	4,5
Refurbishment, recycling, and disposal	5,1	5,2	5,3	5,4	5,5

**Figure 2. The relationship between the environmentally responsible product assessment matrix and the underlying information that drives its evaluation. The numbers are the indices that identify the matrix elements. The considerations and desirable actions pertaining to each matrix element are described by checklists and guidelines specific to the type of product under evaluation.**

between dissimilar materials should be avoided, as should collections of screws or bolts of different types and sizes. Rather, snap-fitting parts, interlocking covers, and pop-out fasteners are all important assembly techniques for the modern designer.

Some components of products, or entire products themselves, are inherently long-lived and can often be the base for refurbishment rather than complete disassembly and recycling. A good example is AT&T's Signature Series telephones. Especially designed for several cycles of leasing from AT&T Phone Centers, these telephones have somewhat heavier metal plating than traditional purchased units and can be quickly disassembled; their subassemblies are designed to be efficiently recertified, upgraded, or replaced. After they are cleaned and buffed, phones that look and perform like new are returned to active service, continuing a cycle reminiscent of the decades-long

approach of the now-departed Bell System.

**Design Guidelines and Tools.** AT&T is developing specific design aids to achieve green design within the company. Two such aids are Design Guidelines and the Green Index tool. Design Guidelines have been developed for specific product categories that provide guidance for designers in incorporating environmental responsibility into their products. These guidelines are made available to them through the World Wide Web within AT&T. The Windows\*-based Green Index tool calculates an environmental figure of merit using green attributes<sup>4</sup> that measure the environmental attributes of the product design and of the manufacturing process. Together, the Design Guidelines and the Green Index tool contribute to the framework of green design within AT&T.

#### **A Composite Corporate DFE Assessment**

During the past several years, the authors of this paper and their colleagues have completed nearly two dozen DFE assessments of AT&T products. These assessments obviously do not deal with all products manufactured and sold or leased by AT&T. Nonetheless, they include products as small and inexpensive as electronic connectors, and as large and costly as electronic switching machines, as well as representations of the offerings of several different business units. The papers by L. O. D'Anjou et al.<sup>5</sup> and G. Wightman et al.<sup>6</sup> in this issue describe some specific findings and corrective actions from these assessments. The paragraphs that follow examine another aspect of the assessments: positive and negative factors that are common to almost all of them.

The technique used to perform individual DFE assessments and consolidate the information into a corporate overview is based on an evaluation tool called the Environmentally Responsible Product Matrix. This assessment technique<sup>7</sup> has as its central feature a 5 × 5 assessment matrix with two dimensions: life-cycle stage and environmental concern, as shown in Figure 2. The topics treated by the matrix are discussed in detail elsewhere.<sup>8</sup> In use, the DFE assessor studies the product design, manufacture, packaging, in-use environment,

**Table II. Combined environmental matrix scores for AT&T products**

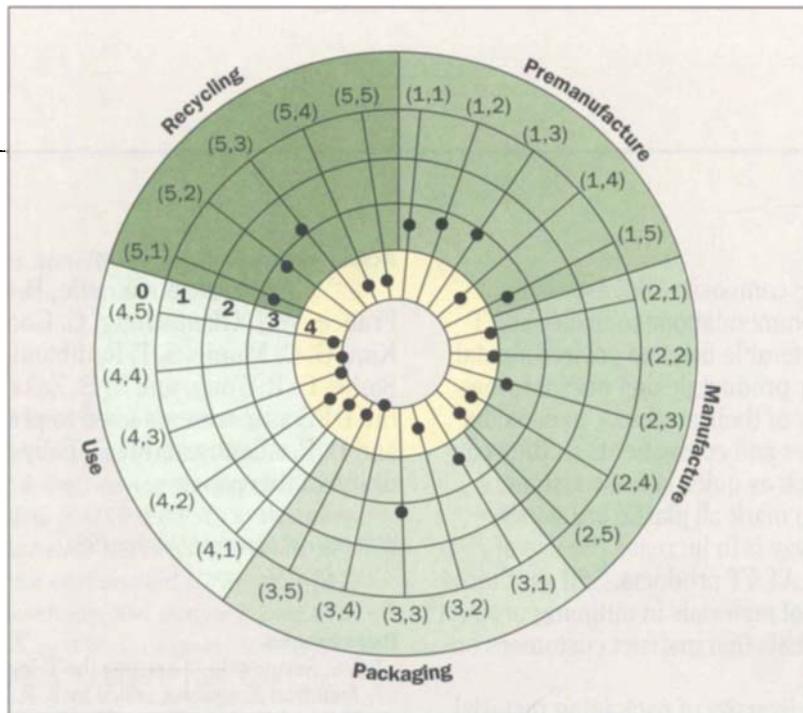
Element designation	Element value and explanation
<b>Premanufacture</b>	
Materials choice (1,1)	2.3 (Recycled materials seldom used)
Energy use (1,2)	2.2 (Substantial energy use in intercontinental transport)
Solid residues (1,3)	2.0 (Little attempt to minimize packaging volume or diversity)
Liquid residues (1,4)	3.4 (Only minimal residue produced)
Gas residues (1,5)	2.5 (Substantial emissions from intercontinental transport)
<b>Product manufacture</b>	
Materials choice (2,1)	3.1 (Lead solder used, but waste lead tightly controlled)
Energy use (2,2)	3.1 (Wave-solder machines use significant amounts of energy)
Solid residues (2,3)	2.8 (Some solder paste residues produced, but effectively handled)
Liquid residues (2,4)	3.3 (Low-solids flux residues must be chemically neutralized)
Gas residues (2,5)	3.3 (Only minimal residue produced)
<b>Product packaging and transport</b>	
Materials choice (3,1)	2.6 (Two materials generally used—one is preferred)
Energy use (3,2)	3.5 (Only minimal energy use)
Solid residues (3,3)	1.7 (No recycling instructions; some packaging not recyclable)
Liquid residues (3,4)	4.0 (No residue produced)
Gas residues (3,5)	3.9 (Only minimal residue produced)
<b>Customer use</b>	
Materials choice (4,1)	3.7 (No concerns)
Energy use (4,2)	3.3 (Products generally have modest energy use)
Solid residues (4,3)	3.9 (Only minimal residue produced)
Liquid residues (4,4)	4.0 (No residue produced)
Gas residues (4,5)	3.8 (Only minimal residue produced)
<b>Refurbishment, recycling, disposal</b>	
Materials choice (5,1)	2.1 (Lead present on printed circuit boards)
Energy use (5,2)	2.1 (Significant disassembly costs for labor and energy)
Solid residues (5,3)	1.7 (Designs offer little opportunity to reuse materials)
Liquid residues (5,4)	3.7 (Only minimal residue produced)
Gas residues (5,5)	3.6 (Only minimal residue produced)

and likely disposal scenario. She or he then assigns each matrix element a rating from 0 (highest impact, the most negative rating) to 4 (lowest impact, the most exemplary rating). In essence, the assessor is providing a figure of merit to represent the estimated result of more formal life-cycle inventory analysis and impact analysis stages. He or she is guided in this task by experience, a design and manufacturing survey, appropriate checklists, and other information. The process described here is purposely qualitative and utilitarian.

In arriving at an individual matrix element

assessment, or in offering advice to designers trying to improve the rating of a particular matrix element, the assessor can refer for guidance to underlying protocols and checklists specific to the product or product line being evaluated. Figure 2 illustrates the relationship between the matrix and the supporting information.

Each assessment of the environmental responsibility of an AT&T product results in the assignment of values to 25 matrix elements, the matrix index  $i$  referring to life-cycle stages and index  $j$  to environmental concerns. Given  $n$  individual product assessments, composite matrix



**Figure 3. A composite target plot for AT&T products. The dots closest to the center of the “target” represent the best results. Product management teams can quickly identify areas that need improvement because they fall outside the central “bull’s-eye” area.**

element values can be derived for a corporation’s products by performing the operation:

$$M_{i,j}(AT\&T) = \frac{\sum M_{i,j,n}}{n}$$

The index  $n$  refers to the results from an individual assessment, and no attempt has been made to apply weighting factors based on product sales volume, cost, or other “external” factors to the individual assessments. This process gives the ratings shown in Table II, where the comments refer to the principal factors responsible for reducing the matrix element values from the maximum score of 4.

If these scores are summed over all life stages and all environmental concerns, the result is an overall rating for AT&T telecommunications products of 75.6 out of a possible score of 100, certainly commendable, but also leaving plenty of room for improvement.

A succinct display of the matrix element results can be shown in a “target plot,” in which a good product or product group shows up as a series of dots bunched in the center, as would occur on a rifle target in which each shot was aimed accurately. To construct the target plot, the values of the elements of the environmentally

responsible product matrix are plotted as sequentially increasing angles that are multiples of  $360/25 = 14.4^\circ$ . The plot makes it easy to single out points far removed from the bull’s-eye and to mark their topics for special attention. Product management teams can then concentrate on improving individual matrix element ratings.

Figure 3 shows a “corporate target plot” for AT&T products, constructed from the composite matrix element values. It indicates that AT&T manufacturing processes are generally exemplary from a DFE standpoint, with room still existing for minimizing solid residues and water use. Also on the positive side is the minimal level of environmental impacts during AT&T product use, though certain products could decrease their level of energy consumption further. In contrast to these favorable attributes, several corporate-wide DFE product characteristics tend to be less than exemplary. These include impacts from virgin materials use, the volume and diversity of supplier packaging entering AT&T facilities, the environmental impacts (energy use and gaseous emissions) of intercontinental shipping of components and products, the volume and diversity of packaging used by AT&T in its products, the use of lead-containing solder, and the minimal design for disassembly characteristics.

### Recommended Activities

The results of the composite DFE assessment suggest a number of recommendations to make AT&T products increasingly preferable from an environmental standpoint. One way is for product design organizations to improve the modularity of their products, to consider redesigning subassemblies and components so they can be joined with devices such as quick-release fasteners rather than screws, and to mark all plastic parts using ISO guidelines. Another way is to increase the use of recycled materials within AT&T products. Still another is to minimize the diversity of materials in outgoing product packaging and develop labels that instruct customers on how to recycle packaging.

To minimize the diversity of packaging material entering and leaving the manufacturing facilities and thereby optimize the recycling of solid residues, supply line management organizations should work with suppliers. Purchasing officers should rewrite specifications for incoming packaging material to specify the use of some recycled material in its manufacture. Because transport (especially intercontinental transport) of components and products carries environmental impacts related to energy use and gaseous emissions, the most energy efficient routes and most environmentally benign transport technologies should be used.

### Summary

Designing products with the environment in mind is imperative if human society is to achieve a sustainable future. No product can ever be regarded as not having an effect on the world in which it is created, because product manufacture inherently uses energy to transform materials into new forms and shapes. Nevertheless, electronics products have inherently modest environmental footprints, and DFE assessment is making continual strides toward improvement. As B. R. Allenby and R. A. Laudise<sup>9</sup> describe in this issue, customers are increasingly demanding greener products. The DFE tools described in this paper are helping AT&T's product engineers design and build telecommunications equipment that will delight our environmentally knowledgeable customers.

### \*Trademark

Windows is a trademark of Microsoft Corporation.

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**Thomas E. Graedel** is a distinguished member of technical staff in the Materials Chemistry Research Department at AT&T Bell Laboratories in Murray Hill, New Jersey. He is the co-leader of the AT&T Design for Environment Assessment Team. Mr. Graedel joined AT&T in 1969, after receiving a B.S. in chemical engineering from Washington State University,



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Pullman; an M.S. in physics from Kent State University, Kent, Ohio; and a Ph.D. in astronomy from the University of Michigan, Ann Arbor.

**Paul Reaves Comrie** is manager of the Technology and Environment Department at AT&T Global Manufacturing & Engineering/Environmental Health and Safety (GM&E/EH&SC) in Whippany, New Jersey. He heads the corporate effort to deploy design for environment (DFE) into AT&T products and operations worldwide. Mr. Comrie joined AT&T in 1982, after receiving B.S. and M.S. degrees in mechanical engineering from Cooper Union, located in New York City.



**Janine C. Sekutowski** is technical manager of the Manufacturing Systems Engineering Center of Excellence, located in the AT&T Engineering and Research Center, Princeton, New Jersey. She manages AT&T's Green Products and Processes Research and Development Program. Ms. Sekutowski received a B.S. in chemistry from Kent State University, Ohio, and M.S. and Ph.D. degrees in inorganic chemistry from the University of Illinois in Urbana. She joined AT&T in 1979.

