An Assessment of Design-for-Environment Practices in Leading US Electronics Firms

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A growing number of managers believe that addressing environmental impacts in product-design decisions has tangible advantages to firms. Yet many firms struggle to diffuse design-for-environment (DfE) practices across their product-development teams. Four leading electronics firms' attempts to adopt DfE suggest that the establishment of highly interconnected, internal information networks may be a robust diffusion strategy. Technically competent centers acting as clearinghouses of companywide information relevant to environmental design and coordinated with specialists on individual product-design teams seem to be an effective organizational structure for diffusing DfE. Internal information networks reduce the cost to designers of assessing environmental costs and benefits and thus lower the motivational barriers of product managers. Environmental design tools may be a component of successful DfE practice but do not seem to be sufficient in themselves. The complexity of environmental issues requires an approach that continually generates new information. Dense information networks allow pockets of expertise to form in response to ever-changing needs.

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In the late 1980s, when companies began to eliminate chlorofluorocarbons (CFCs) in their production processes, many discovered that they didn't need CFCs in many cases and could use other less costly materials. Too late, companies discovered that they could have avoided the liability, remediation, and process-change costs associated with the use of CFSs if the designers of their products and processes had only thought ahead and incorporated environmental issues in their designs. To prevent such future costs, many companies began to talk about designing for the environment.

Design-for-environment (DfE) is the explicit consideration of environmental concerns during the design of products and processes [Lenox and Ehrenfeld 1997]. DfE is a natural extension to such quality initiatives as design for manufacturability and design for servicability. Managers see DfE as potentially creating more desirable products at lower cost by reducing disposal and regulatory costs, increasing the end-of-life value of products, reducing material use, and minimizing liabilities. Regulators and environmental advocacy groups see DfE as an opportunity to reduce the environmental impact of industrial activity through the self-interested pursuits of firms. For these reasons, researchers and practitioners believe DfE is a critical component of ecologically sustainable business practice.

Design choices have impacts on the natural environment that are often difficult to assess and depend on a number of factors. Even experts find it difficult to identify what aspects of design will reduce environmental costs or create beneficial opportunities. Plastic may be the right environmental decision in some cases and wrong elsewhere. Emissions of hazardous material may increase liability in some circumstances but not in others. Consumer demand for environmentally benign products has been notoriously difficult to access. In general, it is difficult to make broad rules for green design.

As a consequence, many firms have struggled to include environmental concerns in making design decisions. Faced with dedicating valuable design time to the consideration of environmental issues, product managers are reluctant to adopt DfE practice without a clear indication of its value. In multidivisional firms, this reluctance is exacerbated when other units realize the payoffs from DfE. Incentives often punish product managers for incurring local costs even though their actions improve overall firm profits. Top managers' attempts to motivate design teams to minimize environmental costs are often stymied by their inability to create rewards for good designs or penalties for bad ones.

Efforts to diffuse DfE practice in the business units met stiff resistance.

Even when motivated to design for the environment, product designers are unsure exactly how to proceed. They face an open-ended problem about which information is scarce. Firms typically lack environmental-performance data that is useful to designers. Many firms do not know the composition of their waste streams or the recyclability or reusability of their products. In larger firms, even

when this information is collected, it is dispersed throughout the organization. Ultimately, relating environmental performance to individual design choices and to firm costs and benefits is challenging.

Some firms claim to have overcome these barriers and to have created design systems that incorporate environmental issues. What follows are the stories of four such firms. Each firm is reputed to be a leader in DfE practice. Each is a large, US-based electronics manufacturer. Each is a multidivisional corporation with business units responsible for product design.

AT&T: Spreading DfE by Developing Tools

Environmental management at AT&T, the telecommunications giant, began in 1973 when Western Electric, its manufacturing subsidiary, introduced the company's first environmental policy. AT&T has since reaffirmed its commitment to "the protection of human health and environment in all areas where it conducts operations" [AT&T 1988, p. 1]. But AT&T's activities have not been without environmental impact. In 1987, AT&T was the fifth largest emitter of ozone-depleting chlorofluorocarbons (CFCs). In 1988, AT&T was fined over $1 million for violating US EPA regulations, and AT&T was listed as a potentially responsible party (PRP) for over 20 Superfund sites.

AT&T's venture into designing for the environment began in the late 1980s. In the wake of the Montreal Protocol and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), commonly known as Superfund, a number of engineers began to explore the possibility of addressing environmental issues in the design of products and processes. Although interest began in several divisions (most notably NCR), the effort quickly became centralized within Bell Labs' engineering resource center. For several years, it conducted the effort within a larger program on CFC reduction. In 1990, Bell formed a design-for-environment group to develop the concept and practice of environmentally conscious design.

Initially the DfE group worked to develop and clarify the practice of DfE and win support for the activity. AT&T was a major participant in a DfE task force within the American Electronics Association. AT&T engineers helped organize the IEEE's International Symposium on Electronics and the Environment. The DfE group conducted a demonstration project to design a "green phone" in conjunction with the National Pollution Prevention Center at the University of Michigan. Within AT&T, the DfE group developed a series of design tools, including broad guidelines and checklists, and an environmentally-responsible-product (ERP) matrix for assessing the life-cycle impact of product designs. By 1994, the DfE group had developed a sophisticated software tool, the Green Index, that provides designers with decision support and environmental assessment.

As the DfE group within Bell Labs gained proficiency in applying DfE, a separate group was formed within the global manufacturing and engineering (GME) division of corporate headquarters to promote the use of DfE throughout the corporation. GME tried to piggyback DfE activities on top of other design programs. AT&T had already made substantial in-

roads in implementing similar product-design practices, generally referred to as DfX, where "X" is a place-holder for such concerns as manufacturability, safety, or assembly. AT&T management used the term DfE to emphasize the link to the DfX movement.

While Bell Labs was developing tools for DfE, GME advertised the tools and trained people in their use. Once designers were familiar with these tools, AT&T assumed they would use them. AT&T published DfE guidelines and checklists on its internal network, ran training programs, and conducted product assessments. By November 1995, DfE experts had conducted 20 training and demonstration sessions at the business units. Fifteen of these included an assessment of a local design project using the ERP matrix. AT&T hoped to demonstrate the value of DfE to the business units.

More than 75 percent of the design teams adopted DfE practices.

In some cases, these sessions succeeded spectacularly in identifying a potential environmental problem. For example, one business unit was designing a bypass system for solving telephone infrastructure problems in the developing world. Because the designers expected that electrical power might be interrupted they had designed the system with a large backup battery. The DfE assessment showed that the product would consume four to five percent of the world's lead supply [Anon 1995].

Despite the occasional spectacular success, the program's manager thought that the training and assessments "most of the time—a lot of the time—led to no action" [AT&T 1996]. The business units felt no obligation to respond to environmental concerns. Environmental requirements were not usually written into the design specifications and thus DfE was "the first thing to fall off" [Comrie 1996]. By 1996, there was no evidence that business-unit product-development teams routinely used DfE. During the 1998 restructuring of AT&T, its DfE efforts were reduced. Many DfE resources remained with Bell Labs and became part of Lucent Technologies.

Digital: Using Corporate Experts to Diffuse DfE

Early proactive environment-management efforts at Digital Equipment Corporation, a developer of modern microelectronics devices, were characterized by the same loosely organized, innovative spirit upon which the company was founded. In the late 1980s, Digital facilities began a shift from pollution control to pollution prevention. Interestingly these EPA-award-winning efforts were not driven by headquarters but arose in the manufacturing facilities. The decentralized nature of environmental innovation was further demonstrated by the activities of the reverse-logistics part of the company. In 1990, the resource-recovery center in Contoocook, New Hampshire initiated a cooperative effort with General Electric Plastics and Nailite Corporation to develop a process for recycling the thermoplastic housings of Digital's computers into roof tiles for McDonald's fast-food restaurants.

In the 1990s, changes at Digital diminished its decentralized approach to inno-

vation. Under increasing pressure, Digital closed many of its manufacturing facilities and outsourced most of its production. Digital reduced its manufacturing operations from 45 plants worldwide to about five. With reduced manufacturing (and thus reduced emissions), the environmental health and safety (EHS) staff at Digital shifted their attention towards the environmental consequences of Digital products. According to EHS staff, Digital managers began to recognize the importance of such environmental product standards as the Energy Star designation for computers in the US and the product take-back legislation in Germany. Digital did not want to be at a competitive disadvantage because of the environmental performance of its products.

The movement toward a centralized environmental effort was reinforced during a corporate restructuring in 1994. Digital established the product-stewardship group within the corporate EHS office. One of the group's primary objectives was to disseminate environmental information and expertise to the product-design teams within the newly formed business units. Digital assigned a corporate product-integration manager (PIM) to each business unit to encourage product designers to adopt DfE practices. The PIMs work as liaisons between the corporate EHS office and design teams, providing information, technical assistance, and resources. Many PIMs had engineering backgrounds, and they spent much of their time convincing business-unit managers of the benefits of DfE. The product-stewardship group developed environmental fact sheets to support these scales efforts.

According to both PIMs and product managers, efforts to diffuse DfE practice in the business units met stiff resistance. Business unit managers doubted the benefits of DfE. Our interviews revealed that more than 80 percent of design teams were either unwilling to meet with EHS staff or took no action in response to EHS initiatives. Only one project was reported to be a success. In 1996, the personal computer business unit (PCBU) agreed to allow the PIM assigned to it to sit in on design meetings. At the time, the customers of the PCBU were demanding products with environmentally friendly labels (Energy Star in the United States and Blue Angel in Europe). The PIM was a low-cost way for the business unit to try DfE. The PCBU made design changes to ease recyclability and disassembling the product, and both PIMs and designers viewed the project as a success. The designers were surprised that these changes required minimal effort and little additional cost.

Beyond this project, there was no evidence of routine adoption of DfE within design teams in other units. The PIMs continued to work to promote DfE within the various business units until Digital was acquired by Compaq Computer Company, but designers and product managers expressed only sporadic interest.

IBM: Using Corporate Support to Initiate Voluntarism in Design Teams

IBM, a leading manufacturer of computers, formulated its first environmental policy in 1967. In 1990, IBM won the National Environmental Center's Gold Medal Award for Environmental Excellence. In 1993, *Fortune* listed IBM as a top-10 envi-

ronmental performer [Rice 1993]. Similarly to AT&T, IBM was commended for eliminating its manufacturing use of CFCs by 1993. Between 1987 and 1993, IBM reduced its emissions of hazardous wastes and recycled nearly 70 percent of its nonhazardous waste.

In the late 1980s, IBM, like many other US firms, faced increased regulatory pressure—CERCLA, the Montreal Protocol, and the Superfund Amendments and Reauthorization Act (SARA). In 1989, IBM commissioned an international task force to recommend future environmental activities. The commission established the environmentally conscious products (ECP) initiative to "develop, manufacture, and market products that are safe for their intended use, efficient in their use of energy, protective of the environment, and that can be recycled or disposed of safely" [IBM 1991, p. 1].

By 1996, Xerox claimed savings of over $500 million from its asset-recovery efforts.

The strategy of the ECP initiative was to combine corporate advocacy and support with voluntary activities in the divisions. In early 1992, a senior vice president sent out a message to all business units establishing ECP as a priority for IBM. IBM asked each business unit to assign one member of its product design team to serve as a "strategy owner" for ECP issues. This effort was supported by corporate ECP staff under the vice-president of operations and environmental affairs. This corporate group disseminated and coordinated DfE efforts throughout the company. Technical support was provided by the engineering center for environmentally conscious products (ECECP) established in 1991 and located under the corporate manager of product support services.

Technical personnel at the ECECP maintained expertise in specific technical areas and acted as liaisons to individual business units. In addition, staff at the center conducted research into design alternatives at the request of business units and the corporate ECP office. The ECECP developed general tools and metrics. It held an annual symposium for ECP managers and designers, during which ECECP personnel and various strategy owners described their experiences and learned the state of the art. In addition, the ECECP worked with IBM's materials recovery centers (MRC) to help designers consider end-of-life issues.

Initially, some business units failed to establish DfE. They ignored the request to assign ECP strategy owners or they designated a name for the role but did not change design activity. Others took the initiative to heart and designated effective strategy owners or even devoted resources to creating ECP teams. At one division, a product manager hired four additional engineers to aid the strategy owner. This team worked on specific environmental design issues and helped develop environmental strategies for the product lines.

Over time, largely through the efforts of the research center and the corporate office, more than 75 percent of the design teams adopted DfE practices. In May 1996, IBM released a corporate instruction on ECP that formalized the program that had

existed since 1991. IBM required business units to set up specific infrastructures for DfE and provide reports on progress made towards improving the environmental attributes of products.

Xerox: Infusing DfE Experts into Integrated Product Teams

Xerox, the leading producer of plain-paper copy machines, formalized environmental management in 1980 by establishing an official corporate environment, health, and safety (EHS) organization. In that same year, Xerox issued its first environmental policy statement. Over the next decade a number of events changed the way Xerox viewed environmental management. The 1984 chemical accident at a Union Carbide plant in Bhopal, India, prompted Xerox to begin a worldwide assessment of environmental risks at all its facilities. In 1985, Xerox settled a lawsuit with several families who claimed health problems due to hazardous emissions from nearby Xerox facilities. Xerox was named a potentially responsible party (PRP) at 13 Superfund sites. Increasingly, EHS director James McKenzie began to recognize the need for a proactive approach to environmental issues.

The successful firms provided living specialists to assist designers.

In October 1990, McKenzie and his staff secured support from Xerox CEO Paul Allaire to establish the environmental leadership program, which included a design-for-environment initiative to diffuse DfE practices throughout the Xerox design teams housed in business units. The strategy the corporate EHS office used to diffuse DfE was to provide support for DfE activities on the corporate level while capitalizing on Xerox's use of integrated design teams to establish environmental liaisons at the design level.

The new corporate manager for environmental design and resource conservation in the corporate EHS office provided primary support for the initiative. This manager's role was to advocate and support DfE activities. A group of seven technical staff worked under this manager. The environmental-products-and-technology group, as it came to be known, served a number of functions. First it promoted DfE activities in product teams. One of the mechanisms it used was to perform environmental market analyses to demonstrate the drivers for DfE. In addition, it provided guidelines on how to do DfE. Finally, the members of the group tried to establish personal contacts with business-unit managers and designers.

In one area of DfE activity, asset recovery, the group established contact with design teams through Xerox's integrated product teams. Asset recovery is the take-back, disassembly, reuse, and recycling of products to capture value at the end of their useful lives. For each design prodct, Xerox pulls engineers from various specialties from throughout the company. The environmental-products-and-technology group capitalized on this structure by establishing the asset-recycling-management (ARM) group. This group assigned trained ARM engineers to product-design teams. Instead of entering the teams as outsiders, the ARM engineers became team members in the same fashion as other design

engineers.

ARM engineers provided a number of asset-recovery functions. The mission of ARM was as follows:

> Asset Recycling Management is a Worldwide Asset Recycle organization that provides strategic planning, new product technical support, and environmental linkages to enable development and manufacturing and its customers to achieve corporate priorities through profitable utilization of unserviceable parts and equipment consistent with environmental goals [Xerox 1991, p. 16].

In addition to its product-design responsibilities, the ARM group provided training in asset recovery to other Xerox personnel. It developed a multilevel program geared to individuals' needs (managers, marketers, designers). In addition, it conducted research on specific recycling issues.

Xerox has had much success with its DfE-related programs. In 1996, an internal survey of design teams indicated that 75 percent of projects addressed remanufacturing and other environmental issues in design [Azar 1996]. Xerox products are classified as "newly manufactured" because they include a high content of reworked or recycled components. By 1996, Xerox claimed savings of over $500 million from its asset-recovery efforts while preventing over 1,100 tons of material waste from cartridges alone. A major, new product-development initiative, called LAKES, succeeded in creating a 100-percent-recyclable copier. In the words of one engineer, "The company currently saves hundred of millions of dollars annually through its recycling and reuse programs. The technology built into LAKES, including product take-back, reuse of materials and vastly simplified, waste-free manufacturing processes, holds a lot of promise for tremendous economies in the future, for the long-term sustainability of Xerox" [Ott, Kelly, and Hotchkiss 1997, p. 39].

Lessons Learned

In all four of the firms we studied, corporate managers expressed a desire to spread DfE among the organization's various design teams. Yet only two—IBM and Xerox—appear to have routinely incorporated environmental concerns into a majority of their product-development efforts. By "routinely," we mean that design teams use a set of procedures for analyzing environmental issues in design. What explains these differences? Perhaps the business units of IBM and Xerox were under greater external pressure for improved environmental performance and thus were more likely to implement DfE. With just four cases, this hypothesis is difficult to refute, but a number of indicators suggest this is unlikely. All four firms reported global pressure to improve environmental performance. All four initiated and staffed extensive programs, and, while functionally different, their products have similar technological characteristics and are subject to many of the same environmental concerns.

We believe that the firms' different implementation strategies influenced adoption. Managers in the four firms used two very different tactics to encourage the implementation of DfE (Table 1). One tactic, best represented by AT&T, was to develop design tools that would reduce the cost of green design. The tools were intended to provide designers with a standardized template with which to analyze the envi-

	AT&T	Digital	IBM	Xerox
Background				
Initiative's name	Design for Environment Program	Product Stewardship Program	Environmentally Conscious Products Initiative	Environmental Leadership Program
Year corporate DfE initiative began	1990	1994 (1991 informally)	1991	1990
Initial catalyst	R&D	Environmental Health and Safety	Environmental Health and Safety/Product Safety	Environmental Health and Safety
Motivation for initiative	Lessons from CFCs	Eco-labeling	Changing regulation	Various liabilities
Initial focus	Materials choice	Disassembly	Energy reduction and disassembly	Asset recovery and recycling
Strategy				
Program coordinator	Environmental Health and Safety	Environmental Health and Safety	Product Safety	Environmental Health and Safety
DfE tool development	Extensive	Limited	Moderate	Moderate
DfE specialists	None	Environmental Health and Safety member assigned to design teams	An internally designated design team member	Integrated product team member (from external group)
Technical support	R&D	Environmental Health and Safety	R&D	Environmental Health and Safety, Asset Recycling Management
Product analysis	Environmental Health and Safety, R&D	Environmental Health and Safety	R&D	Environmental Health and Safety
Outcome				
Percent of design teams adopting DfE by 1996 (based on interviews)	<10%	10–20%	>75%	>75%
Examples of product changes	Eliminated lead-intensive product	PCs designed for disassembly Plastics labeled for easier recycling Energy Star compliant	Use of snap-fits on PC housings PCs designed for disassembly Reduced energy use of minicomputers Energy Star compliant	Remanufactured parts incorporated into new machines Machines designed for disassembly Reusable toner cartridges and bottles Energy Star compliant

Table 1: The four electronics firms varied in their strategies for diffusing DfE within their organizations. Xerox and IBM, who integrated DfE specialists directly into design teams and provided substantial technical support to these individuals, had the greatest success in diffusing DfE.

ronmental trade-offs of various design alternatives. The logic behind them was that by lowering the cost of doing analysis, they would make DfE more palatable to designers and product managers. Unfortunately, most of the tools failed to deliver. They were far too time consuming to be useful to designers and often too specific for general design use. Moreover, they did a poor job of translating environmental issues into costs and benefits for the firm. Even when the firm provided the tools "free of charge" and with free training, designers often resisted using them. Some thought them too difficult to use or unworkably simplistic. Others saw them as annoying artifacts of corporate arrogance. For example, telephone designers at AT&T felt that they were familiar with the design specifications and that environmental design matrices were overkill. Moreover, such tools did not take into consideration constraints imposed by manufacturing and thus suggested changes that would require expensive capital investment and dramatic changes in manufacturing. In the "real world, there [was] very little wiggle room for environmental design changes" [AT&T 1996].

The successful firms provided living specialists to assist designers. They established environmental-design specialists within product-development teams to provide information about environmental-design techniques, costs, and benefits. The cases suggest that how design teams are formed influences the diffusion of DfE. Specialists imposed on existing design teams often met with resistance. For example, the PIMs at Digital struggled to gain acceptance within the business units. Xerox formed integrated product teams to meet each new challenge and thus added DfE staff without their being viewed as outsiders. Internal specialists, such as IBM's strategy owners, were more readily accepted, but they took time to emerge because people had to be convinced to volunteer for the specialists roles. To speed the emergence of specialists, IBM provided training and intergroup learning opportunities.

The cases suggest that specialists are more effective when they can go to a dedicated corporate support group for assistance and expertise. In all of the companies, environmental design centers served a number of functions, including product life-cycle analysis, research and development, and information management. For example, at IBM, the engineering center for environmentally conscious products conducted technical research projects for various business units. At Xerox, the asset-recycling-management group provided extensive training programs. In all cases, the important factor for success appears to be the use of effective environmental specialists to integrate these support functions into design teams. While we cannot definitively conclude that corporate support is necessary since we did not observe a case in which a firm established specialists who did not have corporate support, successful integration seemed to occur when the environmental design centers could both collect and disseminate information from disparate parts of the company to the various design teams.

On the Road to Sustainability

Design for environment is one of a growing number of proactive

environmental-management practices that help firms create value for shareholders and reduce environmental impact. Because of the potential for linked benefits, some commentators believe that firms will be motivated by self-interest to move towards sustainable development. Limited government intervention is required and the market will play its traditional role. The proliferation of DfE initiatives in the 1990s suggests that managers see DfE as an attractive mechanism for achieving environmental improvement and profitability—a potential win-win.

Yet our evidence suggests that despite DfE's potential for win-win, it still may be hard to achieve. Many firms are committing themselves publicly to design-for-environment strategies. They have adopted DfE-oriented policy statements and invested in developing and disseminating design-for-environment practices. Yet the reality of implementing environmentally-oriented design changes is far more complex than writers acknowledge. Anecdotal examples of successful DfE programs are few. Perhaps most disconcerting is that, upon closer examination, some of the cases fail to live up to the legends surrounding them.

The news is not all negative though. As evidenced by Xerox and IBM, firms can and do successfully incorporate environmental concerns into decisions on product design. By establishing highly interconnected, internal information networks, these firms diffused DfE practices throughout their organizations. While the evidence is not unequivocal, the adoption of DfE in these firms has led to designs that are both profitable to the firm and greatly reduce the environmental impacts of products.

For institutional actors, particularly government policy makers, the many outcomes of DfE implementations complicate decision making. In formulating policy, government officials must decide whether to employ strong regulatory mechanisms or rely on market and other institutional pressures to change the mix of firm activities towards a sustainable set. To make this decision, policy makers must determine whether the current mixed record of design-for-environment adoption merely indicates the difficulty of implementing proactive environmental strategies or signals a lack of incentives for firms to improve their environmental performance. Our research suggests that even when demand for environmentally benign activities is high, firms have difficulty changing—sustainable practices are still new and not well embedded in firm structures. Our four cases demonstrate that even vanguard companies face formidable barriers to the implementation of new design practices and to the realization of new sustainable products.

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