IMPLEMENTING DESIGN FOR ENVIRONMENT

a primer

developed by

DIGITAL EQUIPMENT CORPORATION

and the

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
PROGRAM ON
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TECHNICAL ASSISTANCE

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Digital Equipment Corporation is pleased to offer this primer on Design for Environment (DfE) as a guide to incorporating DfE concepts into your company. DIGITAL developed this primer as part of its participation in US EPA's Environmental Leadership Program, New England. Through this primer, we seek to facilitate the development of technologies and products that result in reduced generation of pollutants across all media.

DfE is a proactive approach for integrating pollution prevention and resource conservation strategies into the development of more ecologically and economically sustainable products. DIGITAL's DfE program integrates environmental, health, and safety considerations throughout the product life cycle, from development through marketing, manufacture, packaging, distribution and use, to end of life, ensuring that experience and innovation feed back into the design process. The result is fewer hazardous materials and wastes, more reclamation and recycling, and improved profitability.

At DIGITAL, we take responsibility for the complete life cycle of all materials we use and all the products we offer. This primer is intended to share this information and to encourage incorporation of DfE into your company, regardless of the business you are in. Product stewardship reduces business costs and can help companies gain competitive advantage in a global marketplace.

Monica Roll
Corporate Director
Environment, Health & Safety
Digital Equipment Corporation

The MIT Program on Technology, Business & Environment (TB&E) currently maintains research efforts on Design for Environment, Industrial Ecology, voluntary codes of practice, and other approaches to "corporate greening" and sustainable development. Through our research, we aim to educate both students and corporations in the development of proactive approaches to environmental management.

The work on Design for Environment at TB&E--a multi-year project--has involved a number of students and faculty, and attempts to characterize the state of DfE practice in industry. A comprehensive industry survey of manufacturing firms followed by in-depth surveys of leading firms doing DfE has led us to develop a strong institutional knowledge of the adoption of DfE concepts in industry and the diffusion of DfE practice across firms. Our research focuses on the organizational, rather than technological, aspects of DfE implementation.

MIT Program on Technology, Business & Environment researchers Ryan Frazier, Karina Funk, Ben Jordan, and Michael Lenox have worked with Digital Equipment Corporation in developing this primer on Design for Environment. We believe that successful implementation of a company-wide DfE initiative can be achieved by following the steps included here. For more information on our research, feel free to contact us, or visit our home page on the World Wide Web (http://web.mit.edu/ctpid/www/tbe).

John R. Ehrenfeld
Director
Program on Technology, Business, & Environment
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PREFACE

Design for Environment, commonly referred to as DfE, is an exciting new approach that can improve financial, strategic, and environmental performance. This primer serves as a practical introduction to the subject for anyone—manager, engineer, environmental professional, designer—who is interested in implementing a DfE program within their company, business unit, or department. We have designed this document to be useful to a variety of people and organizations. DfE is equally applicable to both product *and* process oriented manufacturing. Much of what is outlined here can be accomplished with a minimal commitment of resources. Even if your firm does not have fancy software packages and legions of environmental engineers, there is much that can be accomplished using DfE methods.

This document is split into two parts. Part One explains what DfE is and the benefits it offers. Part Two focuses upon the *implementation* of DfE. Unlike other sources which focus either on the general definition of DfE or on very specific DfE tools and methods, this primer is intended to help those interested in applying DfE principles and encourage their organizations to successfully embrace and use DfE concepts and tools. We believe this document will help get your firm moving into a new realm of competitive advantage.

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PART ONE:
UNDERSTANDING DESIGN FOR ENVIRONMENT

Design for Environment, or DfE, seeks to eliminate the potential negative environmental impacts that result from a particular product or process through its entire life cycle by systematically assessing, evaluating, and addressing these potential problems during product development. By considering environmental issues during design, problems are addressed at the outset. Traditional compliance methods deal with wastes at the "end-of-pipe," never addressing the source of the waste. DfE designs-out waste so that treatment is unnecessary. Though some product and process improvements can be accomplished after design, the greatest impact at the lowest cost is usually realized only when improvements are incorporated into initial designs. Furthermore, many issues are only effectively addressed during the design phase.

DfE provides numerous benefits on multiple levels. Many DfE programs not only achieve significant environmental improvements, but actually *reduce* total costs or generate additional returns. In addition to lowering costs, DfE provides other competitive advantages. It improves a company's ability to compete in markets where environmental product performance is important. Strong DfE efforts also improve a company's image and help address current and future regulatory issues. A properly implemented DfE program can simultaneously improve environmental and economic performance, satisfying the needs of both internal and external stakeholders.

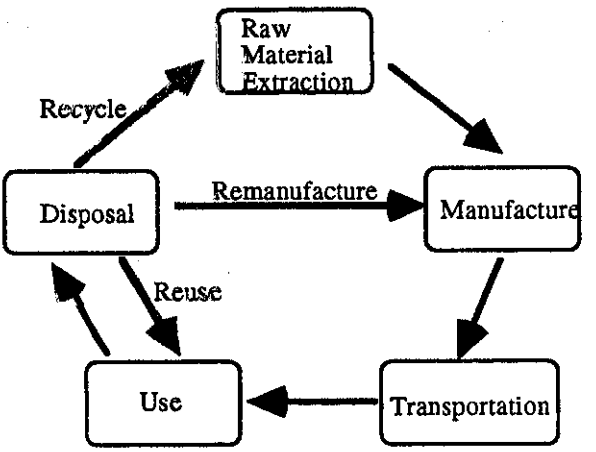
The purpose of this part is to address the "whats and whys" of Design for Environment. Chapters 1 and 2 provide a foundation for a broad understanding of DfE. Chapter 1 looks in depth at what DfE is, and particularly its relationship to typical product development processes and environmental management, the two areas DfE spans. Chapter 2 elaborates upon why a company would wish to implement a DfE program.

CHAPTER ONE: WHAT IS DFE?

Design for Environment is a novel approach to systematically reduce or eliminate environmental impacts throughout the life cycle of a product or process by accounting for potential impacts at the outset and during the continuing course of the design process. DfE is by no means an environmental panacea, and does not address all environmental issues. DfE is not meant to help a company with ex post remediation efforts, does not constitute an environmental accounting system, and is not a guarantor of regulatory compliance. However, a properly implemented DfE program should help to minimize the need to conduct remediation efforts, improve performance as measured by an environmental accounting system, and increase a company's ability to comply with current and future regulation.

Research reveals that few companies' DfE efforts consider the entire product life cycle, but the benefits of DfE can be maximized only if the entire product life cycle is taken into consideration. The product life cycle encompasses not only the traditional time frame of a product, from its manufacture to disposal, but also the activities that enable manufacturing as well as disposition of the product's components at end of life. Typically, the full life cycle of a product is broken down into the five stages shown in Figure 1.

FIGURE ONE: THE PRODUCT LIFE CYCLE



In addition to reducing waste, many DfE efforts attempt to "close the loop" by returning material to earlier points in the cycle through recycling, reusing, or remanufacturing product components and wastes. All of these phases can be dealt with during the design of a product or process through the translation of environmental issues into goals, guidelines, and specifications. For example, product weight can be decreased to reduce raw material input and improve shipping efficiency; components with minimal power consumption or extended life during product use can be utilized; and parts containing only recyclable material can be used.

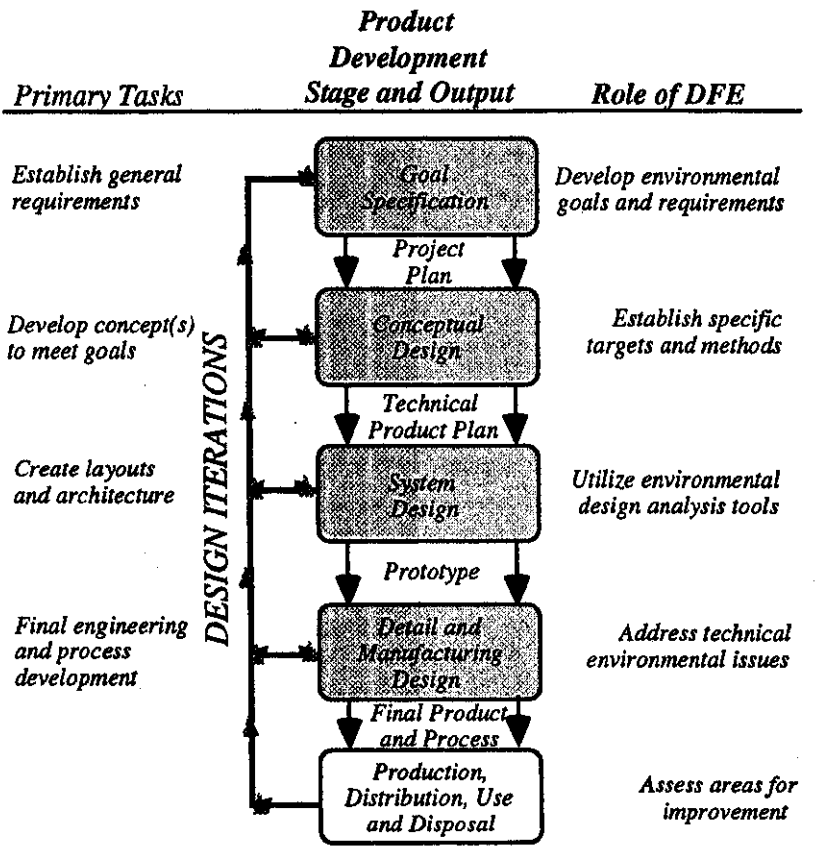
Design for Environment aims to bridge the gap between two traditionally separate functions: product development and environmental management. The goal of DfE is to bring these two functions into closer contact and address product life cycle issues that are often ignored. Considering such issues during the design process can result in a more efficient use of resources, address environmental problems more effectively, and serve as a source of competitive advantage, all of which are discussed in Part Two. Before examining what these benefits are, it is instructive to first consider exactly what the role of DfE is in the product development process and in environmental management.

DfE's Role in the Product Development Process

Typical product development proceeds through a number of stages. Because of the varying nature of each stage, DfE must be handled differently at each step in the process. Furthermore, there are a number of recent trends and experiments on how the design process is conducted which have an impact on DfE and its implementation.

The traditional product development cycle proceeds through four different stages, as diagrammed in Figure 2. When looking at this figure and the following description of each stage, it is important to remember that this is a very simplified and general description of the process. How product development actually occurs in your company is likely to be quite different: different names may be used for design stages, different boundaries may exist between phases, and approaches may be less linear. Nevertheless, all tasks described will probably occur at some point. Look for parallels within your own product development process to which DfE principles can be applied.

FIGURE TWO: THE PRODUCT DEVELOPMENT PROCESS



Goal Specification

In this stage the goals that a product is expected to meet are developed. At this level, the tasks performed during the development process are defined, the problems are outlined, and general requirements and constraints are specified. As one of the most critical stages in the design process, it is also a critical stage for DfE. For example, it could be decided that the product will be 95% recyclable, or that the number of different plastics used will be minimized to improve recyclability.

Conceptual Design

Once the general goals of a product or process have been outlined, more specific plans for achieving these goals are developed. At this phase, a number

of different concepts are usually created and evaluated to find the one that best addresses product goals. This is also a critical step for incorporating DfE concepts, for it is at this stage that the general goals are developed into a realistic course of action. Successful DfE initiatives will add an environmental component to the concept, and provide environmental criteria by which designs are evaluated. To meet the 95% recyclable goal, a decision to avoid engineering thermoplastics (which are difficult to recycle), mark other plastics with labeling codes, and eliminate multi-plastic pieces could be outlined.

System Design

When a specific concept has been selected (or in some instances, when options have been narrowed down to a few possibilities), the next stage is to create a more complete description of the product or process, short of the specific detail work. The fundamental engineering concepts that were established in the conceptual phase are elaborated to ensure that they will be feasible in the context of the product as a whole. When this stage has been completed, a final system layout for the product is produced. At this stage DfE efforts will focus on tools that allow designers to make decisions about how to meet environmental goals. Continuing with the recycling example, engineers could be given lists of acceptable plastics and their relative preference, instructed to design in code markings, and asked to include design approaches that decrease disassembly time.

Detail and Manufacturing Design

In this stage of product development, the layout that was developed is turned into a completed set of engineering drawings and production methods that are used to produce the actual product. No major changes should occur at this phase, as it is primarily to flesh out specific technical details, specifications, and tolerances that will allow the product to be produced. DfE activities at this stage should focusing on helping the designer improve the environmental performance of specific systems, and serve to evaluate final impacts so that environmental performance of future products or redesigns can be improved. DfE also addresses the impact of manufacturing processes on the environment. For example, it may be determined that aqueous cleaning processes will replace solvent cleaning to reduce the amount of regulated wastes.

Recent Innovations

Several innovations in the design process and management of design have recently occurred. The goal of these innovations is to decrease the time and resources it takes to design, manufacture and distribute new product lines. Many of these initiatives can provide a foundation for building a successful DfE program and supports DfE efforts by providing meaningful feedback or information useful to understanding environmental impacts. Some of the more common initiatives include:

- *Concurrent engineering* - This is an approach where the product and its manufacturing process are designed at the same time. Concurrent engineering helps to eliminate inefficient practices that are a source of significant wastes and requires design engineers to consider additional design objectives. Both changes help to promote DfE activities.

- *Design for X* - This is a series of approaches where X represents some particular desired quality, such as manufacturability, assembly, or environment. The premise of DfX is that if additional time is spent in the design stage addressing specific issues it is possible to reduce costs and delays further down stream. DfE may be integrated or added to other DfX initiatives.

- *Parallel or condensed design development* - These approaches reduce time to develop a product either by using a parallel design approach, independently developing different subsystems at the same time, or by beginning future phases in the design process before the completion of the previous phase. Both approaches require considerable coordination. How well they work in conjunction with DfE depends on the "environmental complexity" of the project.

DfE's Place in Environmental Management

Design for Environment is one of a number of emerging practices that attempt to move corporate environmental management beyond reactive regulatory compliance toward proactive strategic management. DfE is an integral part of an effective environmental management system.

Design for Environment is related to and may be integrated with a number of environmental management practices, strategies, and frameworks including sustainable development, industrial ecology, product stewardship, pollution prevention, environmentally conscious manufacturing, and life cycle analysis. Envision DfE as a core activity that enable a number of strategies (e.g.,

pollution prevention, product stewardship, environmental conscious manufacturing). These strategies in turn fit into larger management frameworks such as industrial ecology and sustainable development. In addition, analytical techniques such as life cycle analysis may be a useful tool for Design for Environment.

Sustainable Development

Sustainable Development is an evolving concept which has many possible definitions. One that is widely accepted is development that meets the needs of the present without compromising the ability of future generations to meet their own needs. DfE can be an important instrument for industry to work towards the goal of sustainable development.

Industrial Ecology

Industrial ecology is a framework for understanding the systemic environmental impacts of economic activity. Industrial ecology envisions economic factors embedded in networks. The industrial ecology framework examines systems of producers and users and the linkages of material and energy flows between them. Industrial ecology suggests innovative ways in which systemic environmental impacts may be minimized; for example, the closing of material flow loops through recycling. Industrial ecology provides a useful framework to guide environmental design decisions.

Product Stewardship

Product stewardship refers to the acceptance of some degree of producer responsibility for environmental impacts across the entire product life cycle. Typically product stewardship efforts concentrate on the use and retirement phases so that a product may easily be reused, remanufactured, or recycled. Design for Environment is a useful technique for realizing product stewardship.

Pollution Prevention

Pollution prevention is the elimination of wastes during product manufacturing before they are produced. This is in contrast to pollution control - the mitigation of environmental impacts once a waste is produced. While pollution prevention may be achieved by means other than Design for Environment, DfE is an effective way to design products and processes so wastes are not produced.

Environmentally Conscious Manufacturing

Environmentally conscious manufacturing (ECM) attempts to minimize environmental impacts during manufacturing. ECM subsumes both pollution prevention and pollution control. In the same way that DfE may be used to prevent pollution, DfE may be used to minimize environmental impacts during manufacturing.

Life Cycle Analysis

Life cycle analysis (LCA) is an analytical approach for determining the environmental impacts of products and processes from cradle to grave (i.e., material extraction to ultimate disposal). LCA may be used for a variety of purposes such as individual product assessment, product comparisons, and the identification of environmental impacts. As a product assessment technique, LCA may also facilitate Design for Environment.

Companies are under considerable pressure to have superior environmental performance. These pressures come from a variety of sources:

- Regulators
- Consumers / Customers
- Courts & Litigators
- Advocacy groups
- Suppliers
- Industry groups

Increasingly environmental performance is a prerequisite for doing business. In Europe, legislation is being enacted which requires producers to take-back products at the end-of-life. Eco-labels, which provide consumers with environmental performance data, are becoming de facto industry standards. Environmental management standards such as ISO 14000 are becoming more prevalent.

Historically, industry responded to various pressures for superior environmental performance by implementing costly end-of-pipe pollution control, often failing to recognize the potential opportunities in the proactive mitigation of environmental impacts. Environmental issues were overlooked as a source of competitive advantage. Increasingly, however, companies are learning that profit maximization and environmental consciousness are not mutually exclusive and are beginning to capitalize on "win-win" situations.

Design for Environment when properly executed, may be a significant source of competitive advantage. DfE provides a mechanism by which to achieve strategic objectives such as the differentiation of products, the lowering of costs, the building of core competencies, and the avoidance of future regulation while improving environmental performance.

Product Differentiation

As consumers around the world become more environmentally conscious, they increasingly demand environmentally friendly products. These demands extend beyond manufacturing concerns and include use and end-of-life issues. The impact of these demands extends beyond individual consumers as institutions such as governments and industry begin to require superior environmental performance in the products they purchase. The adoption of Design for Environment allows a company to differentiate its products from its competitor's along environmental lines. In this way, firms carve out dominant

positions within market niches. Environmental quality, like other aspects of quality, can be a distinguishing feature of a product.

Low Cost Production

Pollutants and wastes are inefficient. They represent costs not only in their treatment and disposal but in the materials that go unutilized. Design for Environment is a powerful mechanism for minimizing pollution. Corresponding reductions in production costs can help a company position itself as a low-cost producer within a market.

Building Core Competencies

Many of the skills developed through Design for Environment have positive spill-over effects on other skills. For example, DfE increases coordination between product design and manufacturing where the skills necessary for DfE build on and extend integrative management skills such as concurrent engineering and design for manufacturability. DfE may also increase interaction with suppliers as well as increase strategic communication between corporate offices and business units. Finally, the adoption of DfE can help integrate competencies in environmental management throughout the company which will both enhance traditional compliance functions and better prepare a company to respond to environmental issues.

Avoiding Future Regulation

Companies who merely pursue compliance strategies often find themselves in a continuous cycle of reactive measures to combat regulation and environmental demands. Design for Environment is a mechanism by which companies avoid playing "catch-up" by proactively looking beyond current forces and pursuing activities that better prepare their business for the future. By designing out environmental impacts early, companies may avoid expensive compliance efforts in the future. This allows a company to pursue a variety of market strategies unavailable to compliance oriented competitors.

Improving Environmental Performance - The Other Win

While adoption of Design for Environment helps companies achieve competitive advantage, simultaneous enhancements in environmental performance also result from effective use of DfE. Superior environmental performance is important for reasons far beyond the boundaries of the company. The impact of economic activity on the environment extends beyond mere local issues to far-reaching international problems such as ozone depletion, global warming, and biodiversity reduction.

When properly executed, Design for Environment increases a company's environmental performance and helps mitigate some of the world's environmental problems. In this light, DfE is a powerful mechanism to foster sustainable development and demonstrate that companies are cognizant of the global impacts of their individual actions.

ACHIEVING WIN/WIN SOLUTIONS AT XEROX

Xerox has found that DfE related activities, which have significantly enhanced their ability to reuse, recycle and remanufacture machines at the end of their initial product life, have produced significant gains–both economically and for the environment. In 1995, the company's DfE efforts produced savings exceeding several hundred million dollars, while at the same time reducing the amount of material sent to landfill. Two of Xerox's DfE initiatives have each diverted over 1000 tons annually by utilizing some components up to six times.

PART TWO:
IMPLEMENTING DESIGN FOR ENVIRONMENT

The remainder of this document centers around the question "How do you implement DfE?" From our experience, we believe there is no "best" way to implement DfE within your organization. The issues raised in the next five sections should provide guidance but should not serve as a rigid map. DfE implementation is not merely the adoption of a design tool within product development. Implementation is a multifaceted process involving many stages, many of which may appear peripheral to actual implementation but are actually crucial for success. Part Two is divided into five sections: investigating, measuring, promoting, executing, and diffusing.

- Investigation is needed to understand the context in which DfE is to be implemented. In this phase, the product development process, the products, and the individual incentives for DfE are examined. Up front investigation is useful for setting priorities and identifying levers to aid DfE implementation.

- Measuring the opportunities for environmental improvement and the benefits that derive is a critical part of the DfE implementation process. The identification of benefits helps promote the adoption of DfE as well as directs product development efforts toward favorable design choices.

- It is necessary to gain commitment from product managers before implementation of DfE. Often this requires promoting the benefits of DfE. Promotion is an often overlooked, but critical phase, in the implementation of DfE. Without buy-in, implementation is likely to fail.

- Executing puts DfE into practice. In this section we discuss the various issues in incorporating DfE in the product development process and briefly discuss the use of tools. The key to executing is to understand the various phases of product development and how DfE fits into those phases.

- Finally, in companies with multiple product development teams or business units, it is desirable to diffuse DfE practice across the organization. In this section we discuss ways to establish a corporate wide DfE *program.* Through such a program, policies are set, commitments made, and resources secured.

These phases of DfE adoption, while separate and distinct, should be treated as part of an iterative process that evolves over time. They build upon each other through feedback mechanisms that take advantage of lessons learned. Research

shows that there are a number of successful paths towards implementation. In some organizations, extensive investigation and measurement were necessary to facilitate promotion and eventually execution. In others, promotion and buy-in proceeded investigation and execution. In larger organizations where diffusion is important, investigation, advocacy, and execution interact across multiple product development groups. In general, the interaction between these phases is often dependent on the organizational characteristics of the adopting organization.

Implementation of DfE is dependent on an understanding of the product development context. This context includes not only the development process, but also the product market, individual incentives, the environment impact of a product, and existing programs and capabilities.

While not necessarily the first step in implementation, investigation provides the foundation upon which to promote and execute DfE. A thorough understanding of the design process is needed both to gain support for DfE and incorporate environmental concerns into product designs.

Analyze the Product Development Process

Product development processes vary greatly among firms. Nuances of individual processes determine the salience of various implementation approaches. In order to integrate DfE into the product development process, an understanding of the drivers behind product design is crucial. Knowing where key decisions are made and how they are made is critical. Each actor in the process has expertise relating to the possibilities for and benefits of DfE in his or her own area. This knowledge is potentially valuable to others at different stages of the product development process.

Action Item: Each company has a different approach to product and process development. In a technology-driven company, engineering may drive product requirements. In contrast, the marketing group may be the best focal point for applying DfE principles in a company that is consumer or market-driven. Identify important steps at each phase and the roles of each individual in your company's product development process. Find out what decisions are made at each step, and what influences those decisions.

Research the Product Market

Understanding the market is necessary for directing DfE efforts towards those environmental issues which have the greatest financial impact. The product market greatly influences product strategy and consequently product development. For example, in many industries the rate of technological innovation requires short product development cycles. This consequently limits the time possibly dedicated to environmental design.

Action item: Gather information on the product market and competitive climate, using existing information from marketing and other sources where possible. Secondary market information is available from many sources but primary marketing data obtained within the company will be the most useful.

GETTING TO KNOW PRODUCT DEVELOPMENT: BREAKING DOWN THE PROCESS AT DIGITAL

As a first stage in implementation, DIGITAL carefully examined its product development process. This involved a detailed look at the structure of the product development process. Relevant actors were identified such as Product Managers, Product Marketers, Project Architects, Design Engineers, Manufacturing Engineers, and others (Regulatory Engineers, Service personnel, etc.). Furthermore, the objectives, activities, and key decisions for each role were studied.

Based on this analysis, DIGITAL has tailored its DfE efforts. The appropriate information to support DfE efforts is now specified according to individual roles. Awareness of the different roles in Product Development has also helped DIGITAL identify where DfE initiatives can be most influential.

Identify Life-Cycle Environmental Impacts

Understanding the environmental impacts throughout the product's life cycle can direct DfE efforts to where they are most needed or have the greatest impact. Recall that some of this analysis may have already been done in your company: emissions have been examined through compliance activities while regulated chemicals and hazardous materials have been examined through health and safety activities. For example, an examination of the life cycle may reveal that a product uses a considerable amount of energy during operation. New designs may reduce this demand by improving the efficiency or utilizing a stand-by mode. This change should make the product more appealing to customers and qualify a product for a program such as the EPA's Energy Star, which has additional marketing benefits. A look at the life cycle of a product or process can identify many opportunities for environmental improvement.

Action item: Perform a simple analysis of environmental impacts throughout the steps of a product's life cycle. Brainstorm about ways to improve the product or manufacturing process.

Understand Individual Incentives

Since specific individuals are actually responsible for implementing a company's DfE initiative, it is important to ensure that it is in their best interest to do so. Therefore, creating personal incentives to adopt DfE is important. Some incentives are easily aligned: a visionary marketing manager responsive to green consumer preferences is well rewarded for developing new markets for the company and increasing sales volume and profits. However the reward for a design engineer who is conscientious about environmental impacts and thus designs for disassembly will not be as obvious, as the design may increase *initial* manufacturing costs. If this innovation achieves cost savings at the end of the product's life, how should the engineer be evaluated and rewarded?

Action Item: Understand individual and group incentives for doing DfE. Examine employee performance review criteria. Try to identify ways to motivate individuals to pursue DfE activity.

Investigate Existing Capabilities

Use programs and core competencies that already exist in your company to facilitate DfE. Basing DfE on current company efforts makes it easier for individuals to understand and accept DfE. These programs also provide existing mechanisms for executing DfE. Individuals with expertise in environmental issues, TQEM, or concurrent engineering can communicate their knowledge to decision makers during product and process development. Such outreach encourages acceptance of DfE.

Action item: Identify existing capabilities, programs, and human resources. Look for processes or programs on which DfE can be "piggy-backed" and individuals with unique knowledge or skill bases that are applicable to DfE.

The measurement of environmental improvement opportunities and potential company benefits provides an excellent base for both promoting DfE within your company and to direct design attention toward the greatest benefits or impacts.

Implementing DfE can increase market share and profitability. Unfortunately, it is not always easy to measure and it is often difficult to quantify the potential rewards of environmental design choices. The ability to systematically identify and measure various benefits expedites successful DfE implementation. The major mechanisms for identifying the opportunities include searching for cost saving possibilities, targeting regulations and global standards, conducting market research, and benchmarking.

Identify Cost Saving Opportunities

One of the greatest incentives for implementing DfE is that many of the features can be done at *zero design cost.* For example, designing products that can easily be disassembled, i.e., separated into component waste streams and/or recycled, often involves simple low-tech measures. These features can be included at minimal or no design cost but have the potential for significant cost savings now and in the future. Identifying these low-or-zero-design-cost opportunities may reveal several readily implemented DfE projects.

Action Item: Identify a set of low-tech, low-cost measures such as minimizing the number of different material inputs used, minimizing the number of screws and other fasteners, creating modular designs for easy disassembly, and identifying plastics and alloys with molded or stamped labels for easy recyclability.

Target Regulations & Global Standards

Regulatory compliance is a minimum goal and will not usually guarantee the most environmentally friendly practices or differentiate your product from your competitors'. Future regulations, however, are a significant driver for DfE: by meeting anticipated regulations today, the company may avoid future headaches and differentiate its products at the same time. Awareness of and accountability for the environmental impacts of products and processes is becoming especially important in the global marketplace. Designing a product that can meet international regulations and standards at the outset opens the opportunity to compete in any market.

Action Item: Through library searches, trade groups, and consultants, create a chart of regulations and domestic and/or international standards for your market(s) of interest. Think about which environmental targets on that chart your product can beat at the lowest cost, in a timely manner. Consider other DfE goals for the long term or for upcoming products. Consistently performing above and beyond regulations and standards will send a clear signal about the environmental excellence of your product.

Conduct Market Research

Consumer surveys reveal that although customers are not willing to pay a premium for environmental features, consumers *expect them to be there.* Some consumers may not have an environmentally based product preference until one product is differentiated based on environmental performance. Although not explicit in regulations or standards, large customers (such as governments) may require their suppliers to practice various aspects of DfE to even qualify for bidding. Market research can help establish and quantify the demand for environmentally conscious products. Seek to include questions about consumer preferences for environmentally conscious products into existing customer surveys. This is an example of "piggy-backing" on existing competencies to efficiently promote DfE.

Action Item: Identify and survey key customers or potential accounts about their interest in purchasing "environmental conscious products." Couple this research with information about competitors and markets in general. Analyze data and determine if there may be benefits from environmental initiatives. Communicate established market benefits to the appropriate people in product development. Consider DfE as one way to differentiate a product from competitors'.

Benchmark

Competitor research can augment the market research which identifies consumer preferences. In some industries, companies are quickly embracing proactive environmental approaches. If you can demonstrate that your prime competitors are doing DfE, it will be easier to convince people in your company to follow suit. Furthermore, by keeping an eye on the competition, your company will be able to quickly respond to new innovations. Benchmarking identifies the latest environmental conscious practices which may improve or even go beyond DfE.

Action Item: Stay abreast of recent developments among your competitors. Research trade journals, news articles, and annual environmental reports to learn the current state-of-the-art.

INCREASING FEEDBACK:
IDENTIFYING OPPORTUNITIES AT DIGITAL

DIGITAL's employees at their product take-back facilities know all too well the environmental impacts of their products. They are also very knowledgeable about the features that would make disassembly and recycling much easier. DIGITAL has established a communications link between product recycling operations and product design. DIGITAL assigns end-of-life costs to the responsible business unit. Zero-cost DfE features are then integrated into DIGITAL's product development process. This feedback loop optimizes product and recycling efforts.

You may wish to implement DfE in a product development group but be unable to secure the support of management within the group. In these cases it may be necessary to actively promote DfE. Promotion may occur before, after, and/or concurrently with investigation, measurement, and execution phases. Research has shown that there are several factors which contribute to successfully promoting DfE.

Set General Goals & Strategy

As a first step, set general goals for a Design for Environment initiative. From these goals, develop a DfE implementation strategy. Goals and strategy provide a necessary long-term framework for establishing DfE within a product development team and will help gain management commitment. Promoting overall frameworks and expectations for DfE can help you "win the battle" for DfE support.

Action Item: Hold a strategy formulation session. Generate a "goals" document. Set realistic targets for DfE implementation as well as environmental and economic performance based on DfE initiatives.

Communicate Benefits

Communicating the benefits of DfE is one of the most critical steps to promoting DfE implementation. Setting up information channels to "spread the word" about DfE should be done early in the process. DfE "liaisons" should concentrate on maximizing information exchange among and within product development teams. Useful information includes contact people; books and articles; internal documents such as memos, policies, guidelines and reports; competitor and industry benchmarking studies; and environmental research. Distribution of useful and convincing information is one key to effectively promoting a DfE program. (Refer to Chapter 4 - *Measuring* for a discussion on how to measure benefits.)

Action Item: Set up an easily-accessible DfE "library", either physically or on your company's internal communications network. Provide updates on what's new in the world of DfE both internally and externally. Have examples of other companies' or groups' successes easily accessible.

SPREADING THE WORD AT IBM

IBM recognizes that being a leader in industry requires action on all levels, and environment is one of the many fronts in which current consideration is being focused. By communicating benefits of its DfE program early in the process, IBM has been able to "sell" the concept to employees.

IBM maintains an extensive library of knowledge about DfE on its internal communications web. The information can be accessed by anyone in the company, and includes, for example, checklists of things to consider when designing for the environment.

Leverage Existing Structures

Each company has its own unique characteristics - levers - which can be used to catalyze DfE. These levers are associated with the product development process, the characteristics of the product itself, decision-makers in the development process, and the existing programs and capabilities of the company. Using these levers facilitates the implementation of DfE by exposing the most effective points for introducing and spreading DfE practices. (Refer to Chapter 3 - *Investigating* for a discussion on how to learn about existing structures and capabilities.)

Action Item: Build support from the ground up. Identify individuals with an interest or incentive to adopt DfE. Familiarize these individuals with DfE and secure their support.

CHAPTER SIX: EXECUTING

With the information gained from investigations outlined in Chapter 3, benefits measured as discussed in Chapter 4, and support marshaled as discussed in Chapter 5, it is possible to move into the design process. Though these first steps may not seem to be part of DfE proper, avoid the temptation to move directly to the design step. The knowledge gained from preliminary studies forms the foundations upon which effective changes to the design process are made. However, there may be instances where such investigations and backing are not possible or available. In such a case, it is still possible to follow the suggestions in this section to achieve improved designs, which may help in garnering future support. Regardless, careful preparations will be repaid with less resistance, quicker success and more substantial improvements.

Consider Environmental Impacts as Early as Possible

When beginning a DfE initiative, it is often tempting to start by providing DfE tools to design engineers. However, it is unlikely that designers will initially be able to make use of the various tools. Designers are motivated by product requirements and specifications developed during the goals specification phase, not by the availability of tools. Therefore, a more successful approach is to integrate environmental objectives into product goals and requirements.

It is critical to the success of DfE efforts to consider environmental impacts and opportunities as early as possible in the product design process where they apply the greatest leverage. At the outset, incorporate environmental features that have a clear benefit and/or can be added at no cost. Incremental successes will establish a collaborative relationship with the product team leaders, and pave the way for future DfE initiatives.

Action Item: Establish a "DfE Champion" on the product development team. This does not need to be that person's role, but it is important that there is a "point person" to insure proper consideration.

Participate in Goal Specification Stage

At the initial goals specification stage, address environmental issues - just as marketing, manufacturing, and development issues are. Someone with a clear understanding of the way that products and process affect the environment should help develop environmental design goals. At this stage such design goals are likely to be very broad, such as minimizing materials, considering end-of-life handling, eliminating excessive packaging, and/or making other

environmental improvements. It is also wise to prioritize the various goals based upon preliminary assessments. The goal at this stage is to make sure that environmental considerations are on the table for discussion and are incorporated into the final product specifications.

Action item: Assess a current product and recognize features already incorporated. Pioneer some modest DfE goals in a follow-on product or process development initiative. The DfE representative should come into initial design discussions with a list of environmental goals.

Develop Environmentally Sound Design Concepts

At the conceptual design stage, the broad goals adopted in the product definition stage need to be expanded to provide design specifications. The greater the detail of these specifications, the more likely significant results will be achieved. A goal of "minimize disassembly time and effort" may result in specifications about snap and clip fasteners, minimization of the variety of materials used in production, imprinted part labeling, reuse/recycle/remanufacture codes, or other alternatives.

Action Item: Provide product designers with pertinent information in a format consistent with other specifications. At this stage it is advantageous to have consulting designers well versed in environmental issues to help assess concepts.

Produce Environmentally Sound System & Detail Designs

In the final stage of design development, many of the environmental issues already have been dealt with. However, there are many decisions that are typically left to designers that may have negative environmental consequences. For example, the use of adhesive labels can hamper the recyclability of materials. This is typically not a high level design issue, but is nevertheless important for designers to know. This detail highlights the need for both training to inform designers and tools that can elucidate such issues. Again, consulting environmental experts can be of use.

Action Item: Provide designers with a checklist to help them meet environmental criteria and goals. Train designers so that they are aware of seemingly "unimportant" technical details that may have significant environmental impacts. Encourage the use of environmental experts.

SETTING DESIGN SPECIFICATIONS AT XEROX

Xerox has realized that developing environmental specifications is an integral part of successfully implementing DfE. Over the course of the last several years, the team responsible for championing DfE has developed a formal set of environmental specifications. This document is in the same format as all of the other design guidelines that are distributed within the company. They outline specific performance criteria in a number of different areas, and the significance of meeting them. Some of these address current regulation, others anticipated future regulation, and some target standards that must be met to qualify for different environmental excellence awards and labels. These design standards have been distributed world-wide and are also available on the companies internal network. Furthermore, there are specific individuals who have responsibility for assessing and addressing environmental issues at each step along the design process. Passing the environmental review is also a prerequisite for a project advancing to the next phase along the product development process. All of these efforts have made environmental issues an integral part of Xerox's design process.

Include Environmental Issues During Formal Design Reviews

Take similar actions at the design review and assessment phase. Specific targets must be identified and verified to ensure environmental parameters are met. Again, it is helpful to have the specific individual or group responsible for these issues use established design review procedures.

Action item: Assign someone to evaluate the design so as to ensure compliance with environmental goals and specification. Be on the look-out for major environmental impacts not initially anticipated.

Design For The Entire Life Cycle

It is helpful to remember to design for an entire system, not just a product. This system includes procurement, production, distribution and disposal. Though not explicitly designing these other systems, the choices that are made during product design will have substantial impacts upon all of these areas,

which in turn all have associated environmental effects. Try to keep these other issues under consideration throughout the design process.

Action Item: Product packaging is usually overlooked as an area for DfE because it is usually designed after the product is designed and built. Bring together the packaging and product designers to discuss how, together, they can improve environmental performance.

Learn From Current Efforts: Continuous Improvement

As you proceed through the design process you may discover unanticipated environmental impacts, but be too far along to design them out. This should not be reason for despair, as the implementation of DfE is a learning process. Use the knowledge gained from the current "mistake" to improve goals and specifications during the next round of design. Seek to always improve performance, environmental or otherwise, and learn from the process.

Action Item: Adopt a formal feedback process to enhance the learning ability of your company. Any person along the product development chain should communicate deficiencies that they are unable to address to the DfE champion. These issues should be used to help design follow-on products or in new designs.

Choose Effective Tools

To assist with the process of implementing Design for Environment, a number of analytical tools can be employed. These tools range from complex, data intensive, computer-based analysis programs to simple checklists, guidelines, or scoring matrices. Before considering tools, determine which steps in the design and implementation phases would benefit most. Then consider the general applicability of the tool to the areas of need, and examine the specific support and implementation requirements.

DfE tools are varied. Though a review of specific products is outside the scope of this document, at the end of the primer we provide references to articles that discuss different approaches and contact information for some of the available computer tools. Three primary attributes may be used to classify Design for Environment tools (Figure 3):

- *Applicability to product development stages* - Some tools are useful only for generating product goals, while others assist in developing detailed designs. Consider the intended place and user of the tool in the product

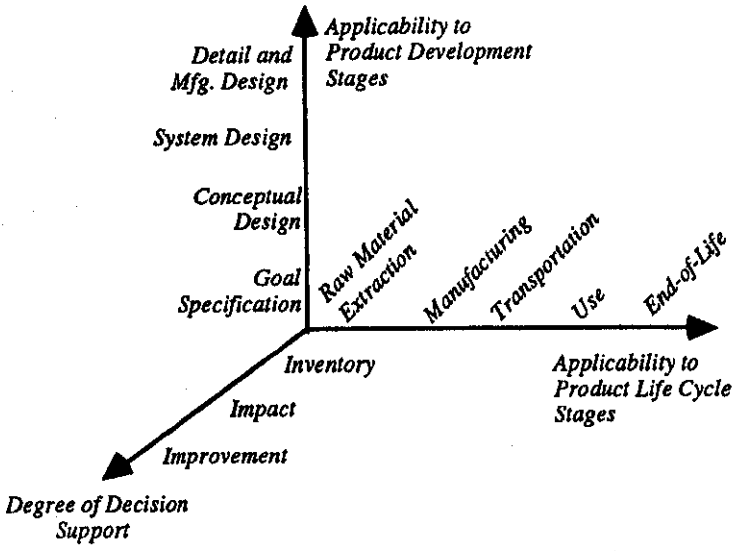
development process.

- *Applicability to product life cycle stages* - Though, ideally, all stages of the product life cycle are considered, most tools are not that robust. Consider tools that address either the stages over which you have the greatest control or where the largest impacts occur.

- *Degree of decision support* - This dimension describes the type of output data that the tool generates. Inventory tools generate raw data on the environmental attributes of a design; impact tools aggregate this data to provide an assessment of the environmental impacts; and improvement tools facilitate the selection of alternative designs and design characteristics to reduce their impacts. Determine the level of information that is appropriate to your task at hand.

In addition to classifying tools, match the type of tool to what you wish to accomplish using that tool. There are a number of issues to consider to make sure that the tool you choose is useful to your organization.

FIGURE THREE: CLASSIFICATION OF DFE TOOLS



- *Tool sophistication* - Match the need to the tool and the tool to the user. Various tools have different purposes and require different levels of user sophistication. For example, designers are looking for tools that

summarize an entire product. Manufacturing engineers, however, are interested in detailed, focused tools that measure their goals. Some people are drawn to simple tools, like checklists, while others find sophisticated software programs more useful. The correct tool is the one that provides the most benefit to the person using it.

- *Cycle time* - The amount of design time available, and the length of time that a product will be in service, both influence the type of DfE tools appropriate for use. Lengthy development times allow the use of data-rich programs, such as complex life cycle analyses. Furthermore, products with a long life may warrant additional examination of impacts that occur during their use.

- *Resource availability* - Resource constraints pose two impacts: limiting the ability to obtain or develop a tool in the first place, and limiting a company's ability to properly utilize a tool. Given that there is much that can be done with minimal up-front investment, carefully spend precious development dollars on the latest tools.

- *Product complexity* - Particularly complex products may result in some tools being unusable or perhaps overly cumbersome and time consuming. At the same time, complexity may make reliable analysis possible only by using computer-based modeling techniques to elucidate non-obvious interactions. However, for simple product designs, a complex computer tool may provide no more insight than using simple checklists or design matrices.

Action Item: Identify tools that are currently available and where more tools are needed. Using Figure 3 as a guide, evaluate available tools to help choose those that best match your goals and objectives, and identify areas when additional tools are needed. Start with simple tools and work towards the more complex. After determining which tools might be useful, test them within product development and manufacturing. Make sure that the tools are not only appropriate to the task, but appropriate to those who elect to use them.

In companies with many product development groups and business units, it is desirable to implement DfE across the organization. For such companies, the diffusion of DfE practice across product development teams is an important component in the adoption of DfE.

Before the adoption of DfE on a day-to-day basis at the product development level can take place, steps need to be taken to ensure a successful organization-wide *program*. Establishing program goals, obtaining commitment of top management, securing resources, capitalizing on existing programs, and measuring DfE program successes are important components. Remember, elements of this program may have been accomplished already on a smaller scale. The following sections serve as a guide to ease program implementation.

Establish Program Goals

DfE program goals derive from the company's environmental management strategy. For compliance-related strategies, the objective is simply adherence to current regulations. Even in some proactive organizations, DfE is inherently compliance-driven, with companies focusing on complying with future regulations. However, most discussions of DfE implies that it is a "beyond compliance" initiative. In either case, set goals for specific products, business units or divisions. Alternatively, time-oriented milestones in the form of yearly strategic goals or policy implementation achievements may be more applicable.

Action item: Bounce ideas for initial goal definition off others who have experience in a variety of fields. This may include product and production managers, designers, marketers, strategic policy-makers and senior managers. Initial presentation is important: it may decide whether the DfE program finds eventual success.

Gain Commitment of Top Management

Top management must "buy-in" to any company-wide DfE initiative. Though there are examples of DfE diffusion without significant influence from top management, commitment from top management sends a signal throughout the organization that the initiative is worth the time needed to implement. As the product development process compresses due to rapid technological innovation and competition, product developers only have time to consider attributes that are important to the organization as a whole. Therefore, demonstrated

op management ensures that DfE is met with optimism rather
.e.

Action item: Be aware of the needs of the organization and how DfE might help to meet them. Relate stories of similar initiatives that have been successful. Scan the newspaper or trade press to find examples of "win/win" situations in other companies where profits have been made from DfE-type activity.

Secure Resources

Securing the resources required to develop a sound DfE program can serve two purposes. First and foremost, it can ensure the proper allocation of money and personnel towards Design for Environment initiatives at the product development level. Second, akin to obtaining top management commitment, having significant resources signals the organization that DfE is a worthwhile endeavor. Securing resources for a DfE program may be less difficult if such an initiative is combined with others already in place. Many organizations with DfE programs have "piggy-backed" off existing corporate programs. Product safety and quality initiatives are the most common corporate-level programs that have been used to help ease DfE into the product development process. In fact, some companies have extended the role of product safety and quality personnel to cover Design for Environment as well, at both the corporate and business unit levels.

Action item: Look for similar programs to help launch DfE in your company. Implementation of DfE should not be "reinventing the wheel."

Diffuse DfE Incrementally

In its most direct form, diffusion may involve the development of specific corporate requirements applicable to all business units. Research suggests, though, that the most efficient approach to diffusing DfE is incremental. For example, focus on high impact and high opportunity business units first. Move DfE incrementally from business unit to business unit. One advantage of this approach is that DfE practice is refined along the way. Learning from experience increases the likelihood for success in future cases. Furthermore, successful organization-wide implementation is enabled by building momentum. Creating linkages between individual product development groups to break communication barriers will help build this momentum.

Action item: Find a DfE champion in each business unit. Their role is to carry the banner of DfE in their product development group. Integrate this person with designers on the product development team to ensure that communication linkages are optimized.

Provide Training & Education

Providing training and education for those involved with Design for Environment will raise the competencies of product development staff, including champions, as well as raise awareness among other organizational participants. Such training will also help overcome resistance to the adoption of DfE.

Action item: Develop a set of workshops geared to particular functions. Conduct a short seminar on creating competitive advantage through DfE for business unit managers. Provide more extensive training for designers and engineers.

Incorporate Technical Staff

Ultimately, DfE is a technical activity. Incorporating engineering staff into the DfE program team will provide a valuable resource to individual product development teams. Engineering staff can perform a variety of functions including conducting product assessments, investigating environmental design problems, and providing technical assistance. Furthermore, engineering staff help legitimize DfE efforts among engineers and designers.

Action item: Establish a corporate level R&D center for environmental design. Use individual DfE champions to provide a bridge between product development efforts and the R&D center.

Establish Standards

On occasion, an organization might set very specific product environmental improvement standards for designers and developers. Ends-oriented goals such as "100% recycled plastics in all products by 2005" may be set in a classic top-down approach. Top-down initiatives are appropriate in an organization where specific standards and objectives, rather than general strategic goals, have the greatest likelihood of creating change. Corporate culture will dictate whether this is the case within a particular company.

Action item: Allows business units to establish their own process for implementing Design for Environment on the product development level. Provide standards as a benchmark for individual efforts.

Measure Success

While there currently exists no standard measure of Design for Environment implementation, consider ways to measure the success of company-wide DfE diffusion. Measurements may be quantitative, such as cost/benefit analysis or standards compliance. Qualitative review of continuous improvement goals, product environmental improvements, and employee commitment may be more appropriate and easier to measure.

Action item: Periodically audit the extent of implementation within each business. Use the audits to create competition among business units to be the most advanced practitioner.

INCREMENTAL SUCCESS AT IBM

An incremental approach to DfE has worked quite well for IBM. While the company established a DfE program on the corporate level, this program does not detail the actual process for implementing DfE on the product development level. The various divisions within the company have been given the freedom to develop their own procedures for carrying out DfE objectives–procedures that vary depending on the size and structure of the individual division as well as the product line(s) it develops.

Consequently, business units have responded to the corporate DfE policy in a variety of ways. Most of the business units have been successful in making significant environmental improvements to products. Business units that haven't been quite as successful as others are given the opportunity to learn from the "shining stars" at an annual conference of company-wide DfE managers and engineers. This yearly conference is organized by a corporate R&D center for DfE, which also serves the purpose of informing the various business units about environmental design options, while taking steps to verify, or approve, business units' proposed technical options and alternatives to current design practice.

This primer is intended as an introduction to DfE principles and as a guideline for DfE practices. By now it should be clear that DfE need not be a cumbersome, overly complex undertaking. Some simple activities can carry a large benefit for your company's competitiveness and the environment. A reasonable interpretation of DfE is that it will reduce the environmental impacts of products through a system of design that integrates environmental considerations with those of performance, cost, and quality.

Whether your company is large or small, product or process-oriented, this primer should help get you started with a DfE initiative. Production methods and management styles may differ, but there will always be opportunities, and a need, to adopt DfE. The more proactive your approach to DfE, the better position your company will be in to efficiently deliver environmental performance, and not just respond to the demand for it.

We hope that you will continue to refer back to this document for ideas on how to implement and expand your DfE program. As your knowledge and understanding grow with experience, your own ideas and initiatives will go well beyond the current literature on DfE. Keep the DfE initiative at the forefront of your business endeavors, and we wish you well.

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http://www.ce.cmu.edu/GreenDesign/

MIT, Technology Business and Environment Program:
http://web.mit.edu/org/c/ctpid/www/tbe/synopses.html

US DOE Pollution Prevention by Design Program:
http://w3.pnl.gov:2080/DfE/home.html

US EPA Energy Star Program:
http://www.epa.gov/GCDOAR/EnergyStar.html

UC Berkeley, Consortium on Green Design and Manufacturing:
http://www.me.berkeley.edu/green/cgdm.html

University of Michigan, National Pollution Prevention Center:

http://www.snre.umich.edu/nppc/

University of Windsor, Center for Environmentally Conscious Design & Manufacturing:

http://cobra.esxf.uwindsor.ca/ecdm_lab.html

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