AMERICAN ELECTRONICS ASSOCIATION

TOTAL QUALITY COMMITMENT | LEADERSHIP IN TECHNOLOGY & MANUFACTURING | COMPETITIVE U.S. FINANCIAL ENVIRONMENT | GLOBAL MARKET ACCESS | WORLD-CLASS WORK FORCE & WORKPLACE | GOVERNMENT EXCELLENCE IN PROCUREMENT

The Hows and Whys of Design for the Environment

A Primer for *Members* of *the American Electronics Association*

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Introduction

The purpose of this pamphlet is to introduce the concept of “Design for Environment”, explain why it is important to your business, and give you some ideas about getting started. This pamphlet is the work product of AEA’s DFE Task Force, which developed these white papers to help AEA member companies in understanding and implementing DEE.

Once you have read this, you may want more detailed information. If so, you can call Theresa Pugh, AEA’s Director for Environmental Affairs (202-682-4455). For further information concerning the AEA DFE Task Force, contact the Chairman, Brad Allenby. Brad can be reached through the AEA at the above number.

Major contributions to this effort were made by Brad Allenby (AT&T), Jack Azar (Xerox), Bob Goessman (IBM), Steve Greene (Polaroid), Tom Morehouse (USAF), Bruce Paton (Hewlett-Packard), Alec Sarpe (Hughes Electronics), and Jan Sekutowski (AT&T). AEA gratefully acknowledges the contributions of these executives to this effort.

White Paper #1
What is "Design for *Environment? "*
by Brad Allenby (AT&T) and Theresa Pugh (AEA)

<u>WHAT IS "DESIGN FOR ENVIRONMENT", OR DFE?</u>

Briefly, DFE is a method by which environmental considerations and constraints can be integrated into existing process and product design practices. Implementation of DFE will help your company create environmentally preferable processes and products, while maintaining product price/performance and quality characteristics. Even if you don't design products or processes yourself, you may benefit if your suppliers adopt such practices.

Many firms feel lost amid the proliferation of environmental requirements, many now impacting their internal factory operations. At the same time, sophisticated customers are beginning to demand environmentally preferable products, or require use of environmentally acceptable manufacturing processes. Companies that learn how to manage these seemingly chaotic requirements will enhance their competitiveness; those that fail to do so will not survive.

DFE is a down-to-earth strategy for organizing and managing these challenging demands. It is intended to be a module of the existing design system known as "Design for X", or DFX, where "X" is the desired product characteristic (manufacturability, test-ability, safety, etc.), although it can be integrated into any design process. It is not something that may be available someday; rather, you can - and should - start on aspects of it now.

<u>WHY SHOULD I DO DFE, ANYWAY?</u>

There are a number of good reasons why you should add DEE to your list of critical activities. They include:

- Compliance with the multitude of environmental rules and regulations is becoming increasingly difficult and expensive. Firms that learn how to minimize these costs -- and avoid associated civil and tort liabilities -- will increasingly gain a competitive advantage. More than that, some types of environmental regulation -- such as the proposed German legislation which would require electronics manufacturers to take back and refurbish/dispose of/recycle their products post-consumer -- simply can't be managed by traditional end-of-pipe methods. This expanding "new breed" of environmental law will require DFE.

- Customers, both big and small, are increasingly demanding environmentally preferable components and products. The public is armed with new data about emissions and increasingly intolerant of environmentally inappropriate manufacturing practices. Sophisticated customers, such as large firms and even branches of the Armed Services, are demanding environmentally acceptable products, both to limit their potential liability and costs, and to ensure that their inputs are not jeopardized because a supplier - you? -- runs afoul of environmental regulations.

- It's the right thing to do. We live in an increasingly environmentally constrained world. Making products which help people save energy, increases their quality of life, makes them more productive, and at the same time minimizes impacts on the environment is simply the right way for the American electronics industry to work.

HOW DO I DO DFE?

How you implement DFE in your firm depends on the specifics of your design process and, more broadly, on your firm's organization and culture. However, the experiences of the members of the AEA DFE Task Force provide some useful tips to help you get started.

In many companies, the design engineers will be largely unaware of existing and readily foreseeable environmental requirements. They may also be reluctant to consider a set of further requirements and constraints that impact important parameters such as low cost; reliable, repeatable quality of products, services or processes; and fast time-to-market. Moreover, the internal mechanisms to provide environmental data to them in a useful form may not exist (in many cases, existing environmental organizations exist to ensure end-of-pipe compliance, not develop strategic information for planners and designers). Accordingly, implementation of DFE in many firms will require cultural and organizational changes, and should not be approached as a trivial process.

Don't despair, though! The implementation process can be encouraged in a number of ways:

- Senior management leadership and support is critical.

- The environmental and safety organization(s) should be evolved to provide timely, useful input on current and foreseeable regulatory requirements, especially those that will directly impact the marketability of the product.

- Customer environmental preferences, practices and requirements should be determined from specifications, publications, direct feedback, market research and other sources.

- Environmental considerations should receive the same emphasis as, e.g., cost, quality, and timeliness in product and process design and evaluations.

- The firm should develop recognition and reward systems for high quality DFE implementation.

- Material specifications and usage should be consistent with national and international consensus standards.

- DFE considerations, including lifecycle costs and planning, must be incorporated into the earliest stages of the product realization process, preferably in the product concept stage (for example, can a potential product be easily recycled?).

- DFE education and training programs must be developed. These may be internal to the firm, outside commercial courses (which don't exist yet), or perhaps seminars and training sessions sponsored by trade groups.

- Vendors and suppliers must be integrated into your DFE process. So must your customers -- in fact, your implementation of DFE should be used as a competitive advantage.

- Design reviews and assessments should be modified to include a DFE assessment.

COME ON, HOW DO I GET STARTED?

Remember, one of the reasons we have the environmental problems we have today is a consistent failure on the part of the public, regulators and industry to think of the environment as a complex system, rather than just a few relatively independent media. Accordingly, the amount of environmental data which should be incorporated into a design decision is substantial. The attached matrix system, which has been designed for in depth DFE analyses, provides an idea of how complex a DFE analysis can get.

In most cases, however, you won't need this level of sophistication. Moreover, when you're just starting out, it may be wise to focus on just a few, very important steps you can take to implement DFE (don't forget, though, that your purpose in implementing DFE is to avoid the oversimplifications of the past):

- *Implement pollution prevention measures.* Reduce waste by ensuring that good housekeeping procedures are used in your facilities, that you are using the least toxic materials that will do the job, that your pollution control equipment is well-maintained, and that you are designing products to produce less waste over time. Data to implement this step can be developed by use of checklists (a sample is attached).

- *Design for Refurbishment*. Make products that you can take back and refurbish to be reintroduced into commerce. As you do this, identify barriers (perhaps local or state acquisition statutes) so they may be addressed.

- *Design for Disassembly* and *Recycling.* It's true that in many cases the infrastructure may not exist to support recycling your product now. But that infrastructure will be developing and, more importantly, critical foreign markets may require you to disassemble and recycle your product in the near future.

- *Identify environmental costs associated with specific processes and products (excess* energy consumption or waste production, potential liabilities, etc.), and drive them into product costing and planning activities (many environmental costs today are simply buried in overhead).

- *Begin to develop environmental personnel who can think* of *environmental issues strategically*. They will be an important corporate asset.

- *Review your specifications and vendor requirements* to ensure you are not causing unnecessary environmental impacts in your supply chain. For example, do you require chlorinated solvents where a "no-clean" or aqueous cleaning system can work just as well?

<u>GOOD LUCK!</u>

As this discussion shows, DFE is not simply a matter of good corporate citizenship - although it is that. It is ultimately a matter of corporate survival, because companies that cannot manufacture in environmentally preferable ways just won't be around in the environmentally constrained world of the future. It is a challenge for us all - but together we can meet it. Let us-know how we can help.

White Paper #2
DFE and Pollution Prevention
by Brad Allenby (AT&T)

Pollution prevention is an indispensable component of any corporate effort to achieve more environmentally appropriate operations and products. Although current practice tends to limit application of the pollution prevention concept to manufacturing and related industrial operations, pollution prevention thinking should also be applied to all lifecycle stages, especially the consumer use and disposal lifecycle stages, for manufactured products. Thus, for example, pollution prevention encompasses the design of products which do not require, or generate, toxics during use and maintenance, and which are not toxic, or do not become toxic, when properly disposed of.

Pollution prevention is generally presented as a hierarchy of choices. In descending desirability, the major options are:

- *Source reduction.* Simply use less and practice good housekeeping. Applying Design for Environment (DFE) principles, this also requires designing products and processes so that less pollution is generated over their lifecycles. If a durable good, such as an airplane or an automobile, has a lifetime of years or even decades, for example, it is quite likely that maintenance requirements, not the original manufacturing operation, will generate the most waste. Good design should minimize such waste streams.

- *Substitute.* Replace toxic materials and processes generating toxic waste streams with less hazardous alternatives. In many cases, this may involve rethinking product design or upstream or downstream process requirements, and replacing existing capital stock; "drop-in" substitutes tend to be rare.

- Recycle. Materials generated during the lifecycle of the product or process which cannot be eliminated should be recycled, reused, or refurbished. For example, maintenance of some electronics equipment, such as copiers, requires periodic replacement of certain functional units. These units should be refurbished and placed back into commerce: where this cannot be done, they should be designed to use recyclable materials, and a return/recycle program developed. Be careful, however; state or federal hazardous waste laws may effectively limit your ability to recycle certain materials or products.

- *Dispose of safely and propmly.* Depending on the country, for example, infrastructure for waste disposal may not be fully developed. It is then the firm's responsibility to ensure proper control and disposal (perhaps in the parent country) of waste streams. This becomes much more difficult in a global economy if the product is one whose maintenance or disposal at end of useful life may generate wastes requiring proper handling or treatment not available in many countries. The only real mitigation strategy under those circumstances is to design such products to minimize production of wastes during the lifecycle, including post-consumer disposal.

HOW TO BEGIN POLLUTION PREVENTION PROGRAMS.

- *Identify the wastes of concern.* Initially, this effort may be focused on the manufacturing process. Later, it should be expanded to evaluate the impacts caused by the inputs to the process or product, the manufacture of the product, its use by consumers, and its eventual disposal.

- *Reduce or eliminate production of the targeted wastes.* A four step approach is useful:

  -- Implement good housekeeping practices for short term improvements.
  -- Substitute less hazardous or less polluting "drop- in" materials, components or processes where possible, providing medium term improvements.
  -- Identify alternate markets for by-products and waste streams so they can be reintroduced into commerce, replacing demand for virgin materials. "Wastes" are simply raw materials for which we have yet to identify a use.
  -- Redesign processes and products to minimize the production of targeted wastes, while avoiding creation of new waste streams, providing long term improvements. Note: it is in particular this last stage which offers the opportunity to use lifecycle analysis and DFE practices to reduce or prevent pollution across the lifecycle of the product or process.

In implementing pollution prevention, be careful that you don't trade an apparent benefit in reduced pollution for greater environmental impact somewhere else in your processes. For example, shifting to an indium-tin solder in lieu of lead solder for an operation may slightly reduce your use of lead, but if the indium alloy requirement for a more aggressive flux mandates that you use a chlorinated solvent cleaning system (which it well may), you may not have achieved an overall environmental benefit, simply shifted the point of impact.

Finally, as you begin to implement pollution prevention measures, check with your state environmental agency, the U. S. Environmental Protection Agency, and your trade groups. Increasingly, such organizations are establishing clearinghouses and databases dealing with pollution prevention opportunities. At the least, they may be able to give you some ideas about where you can go for further assistance and information.

White Paper #3
Design for *Disassembb and Recyclability*
by Robert G. Goessman (IBM)

OBTECTIVE

The objective of the Design for Disassembly/Recyclability component of DFE is to incorporate design for disassembly and/or recyclability into the design process at the earliest stage. The design concepts should allow simple, easy disassembly of products at the end of their useful life with as little labor as possible. The subassemblies and components (e.g., printed circuit boards, materials, plastics, screws), must be easily identifiable and separable. This will result in parts re-entering production flow and materials which can be reutilized as is or recycled into a materials stream. Ideally, implementing Design for Disassembly - Recyclability practices will prevent any part of the product ending up as "scrap" to be disposed of in landfills.

EXAMFLES

The design concepts are not complex and some examples follow.

- All screws should be of similar lead configuration, wherever possible.
- "Snap technology" should be preferred over screw/bolt assembly.
- Threaded inserts as embedments should be eliminated (for plastic recycling).
- All plastic should be clearly marked (by molding, no labels) with ASTM, IS0 or other recognized identifiers to allow for recycling.
- Variations of types of materials in the same design should be eliminated or minimized.
- Plastics should have no paint or sprayed metallics on the surfaces.

POTENTIAL PROBLEMS

The following are some issues that may arise as Design for Disassembly - Recyclability practices are implemented. Depending on circumstances, they may impede your ability to fully implement such practices.

- The design selection process may require "over" designing in one area to minimize variability of parts, types of materials, etc.

- Recycling systems may not yet exist for cost effective design choices. Thus, for example, the cost of recycled materials may be higher than "new" materials. This cost disadvantage will decline as more recycling capability is developed and demand increases; it also implies that an important component of a Design for Disassembly - Recyclability program is a requirement that recycled materials be specified, and used, wherever possible.

- Designers may have difficulty or be reluctant to think in terms of disassembly/recycling, and to specify recycled materials in design specs, at least initially. (Design for Disassembly - Recyclability cannot be implemented just by good Design for Assembly practices.)

- Customer specifications may require revisiting and alteration to permit full implementation of Design for Disassembly - Recyclability practices.

White Paper #4
Design for *Environmentally Sound Processing*
by Janine C. Setukowski (AT&T)

Even though it is the factories that actually produce waste, waste minimization activities are not the sole domain of process and environmental engineers but should also actively involve designers. It is important for designers and engineers to work together to investigate the environmental ramifications of a product early in its design state to ensure that an environmentally sound manufacturing process for that product is implemented. This white paper briefly describes a methodology and some examples for doing just that.

METHODOLOGY

- *Compilation of a Waste Stwam Inventory.* Designing for environmentally sound processing starts with compiling a projected waste stream inventory. The purpose of this exercise is to gather detailed information about various process waste streams likely to be generated as a result of manufacturing activities as envisioned early on, to locate the potential trouble spots from the environmental point of view, and to get ideas on how and where design and/or process changes might reduce the volume and/or toxicity of waste streams.

- *Identification of Waste Minimization and Pollution Prevention Opportunities.* Once the waste stream inventory is complete it should be apparent whether or not opportunities for waste minimization and pollution prevention exist through modification of design, material and/or process specifications.

- *Evaluation of Alternatives.* Once the waste minimization opportunities have been prioritized, it is important to develop a strategy for attacking the waste problem. The following priority scale for eliminating or designing out a certain waste stream is suggested:

  -- eliminate waste streams containing substances that are being phased out, such as CFCs.
  -- do not introduce any new waste streams which may require new discharge permits, modification of existing permits, or off-site disposal.
  -- eliminate or minimize waste streams containing other toxic substances found on the SARA 313, the Industrial Toxics Project (ITP), and the

Toxicity Characteristic (TC) substances list.

- attempt to reduce the quantity of all waste streams, toxic or nontoxic.

EXAMPLES

Many factory waste streams have their origin in cleaning operations. By eliminating cleaning operations whenever possible, one automatically cuts down on the volume of waste. The following recommendations should be considered:

- Substitute more environmentally sound materials and processes for those that are less sound. For example, with respect to post reflow and post wave soldering cleaning operations the following preference hierarchy holds:
  - Eliminate post solder cleaning altogether by the use of low residue solder pastes and low solids fluxes.
  - If reliability concerns don't allow the use of low solids materials, use water soluble pastes and fluxes, and aqueous cleaning.
  - If rosin fluxes must be used and cleaning is required, use semi-aqueous or aqueous detergent cleaning.
  - Avoid the use of other cleaning methods, particularly those based on chlorinated solvents, the use of which should be phased out.

- Sequence process steps in such a way that the number of cleaning steps can be reduced.

- Don't duplicate cleaning steps. For example, if product coming off a production line is sent to storage until it's needed in a subsequent assembly operation, there is no need to clean the product both before sending it to storage, and right after retrieving it.

- Minimize the consumption of de-ionized (DI) water, particularly high grade DI water. A large DI water plant consumes considerable power, and it generates significant waste streams as part of its normal operation.

CONCLUSION

It is important to examine the entire manufacturing process of a product for waste minimization opportunities. This full stream approach ensures that the entire processing sequence is optimized for waste minimization and avoids sub-optimization of individual process steps. Attacking the environmental issues early in the design stage helps avoid costly and time consuming "fixes" during production.

White Paper #5
Design for *Materials Recyclability*
by Walt Rosenberg (CONPAQ) and Betty Terry (Pitney Bowes)

Design for Materials Recyclability (DFMR) is only one aspect of a DFE program, but it is one that can be implemented without too much trouble by most companies in the short term. Firms should consider implementing DFMR in conjunction with Design for Refurbishment and Design for Disassembly/Recyclability, which are discussed in other AEA DFE White Papers.

The range of products produced by electronics manufacturers extends from pocket calculators and telephones to consumer electronics such as televisions, VCRs and stereos to extremely complex computers, avionics and satellite subsystems. Each of these products is a sophisticated, designed mixture of materials including ceramics, frits, glasses, plastics, metals, and combinations of the above. Value in use is high, but the post-consumer product provides little value to a recycler unless she can cost-effectively disassembly the equipment into homogeneous or separable recyclable materials. Materials recycling should be considered a last option, but preferable to disposal as waste. Order of preference:

- Reduce material content
- Reuse components/refurbish assemblies
- Re-engineer (convert and remanufacture used components and subassemblies)
- Recycle materials
- Incinerate for energy (if safe)
- Dispose of as waste

GENERAL PRINCIPLES

There are several general principles which should be kept in mind as DFMR is implemented.

- *Mixed waste streams should be avoided for a number of reasons.* Segregation of mixed wastes is labor-intensive and expensive; mixed wastes may be incompatible with existing recycling technologies (for example, glass or plastics with coatings or films on them frequently cannot be recycled); and mixed wastes containing even a little hazardous material may entail expensive and burdensome regulatory requirements.

- *Effective recycling requires demand for recycled materials* to complete the economic cycle and reduce demand for virgin materials. Therefore, implementation of DFMR should also entail specifying recycled materials where possible; suppliers may need to work with customers to change specification documents that unnecessarily preclude use of recycled materials in either product or manufacturing processes. As the attached chart shows, the material you use in your product is valuable, and can be recycled and reused if your design permits it.

- *In general, thermoset plastics should be avoided if possible,* as their cross-linked structure makes recycling very difficult, if not impossible.

<u>EXAMPLES</u>

The following framework provides a conceptual framework for the designer to begin to implement DFMR:

- *Material Composition*

  -- Avoid hazardous materials and/or materials listed as hazardous by federal, state or local environmental statutes or regulations
  -- Verify component/material status, and potential hazards, by obtaining supplier certification as appropriate (e.g., does it pass RCRA,TCLP or contain heavy metals)
  -- Reduce material diversity in the product:
    ⇒ Limit the number of materials specified
    * Limit the number of fillers within each material or component
    * Limit the number of colors for each material
    * Limit "contaminants" (coatings, films, platings or flame retardants, performance additives -- lead stabilizers in PVC)
  -- Use thermoplastics, not thermosets, and make sure compatible plastics are used in composite structures.

- *Product assembly should be designed with easy disassembly in mind.*

  -- Materials should be identified by label (molded on, embossed, or printed with compatible inks)
  -- Joining should allow disassembly and not mix incompatible materials -- use snap fits, break out inserts, or screws; don't use adhesives.

- *Encourage the use* of *recycled materials in products.*

SOME RECENT MATERIAL RECLAMATION PRICES (circa 6/92)

► *Thermoplastics:*

-- High Density Polyethylene (HDPE) . . . . $.02 - $.05/lb.
-- Low Density Polyethylene (LDPE) . . . . $.0l - $.02/lb.
-- Polyvinyl Chloride (PVC) . . . . $.0l - $.06/lb.
-- Polyethylene Terepthalate (PET) . . . . $.00 - $.03/lb.

► *Engineering Plastics:*

-- ABS (Acrylonitrile, Butadiene, Styrene) . . . . $.15 - $.21/lb.
-- Polycarbonate . . . . $.15 - $.21/lb.
-- Polystyrene . . . . $.15 - $.21/lb.
-- Polypropylene . . . . $.15 - $.21/lb.

► *Thermoset:*

-- Polyurathane . . . . $0.OO/lb.

b *Metals:*

-- Printed Circuit Boards . . . . $50 - $2.55/1b.
-- Ferrous (steel) . . . . $.13 - $.23/lb.
-- Non-Ferrous
Lead . . . . $.08-$.14/lb.
Copper Scrap . . . . $.70 - $l.00/lb.
Tin . . . . $.25 - $l00/lb.
Zinc . . . . $.02 - $l.l4/lb.
Aluminum . . . . $.15 - $.55/lb.

► *Precious Metals:*

-- Platinum . . . . $350.00-$550.00/troy oz.
-- Gold . . . . $330.00-$470.00/troy oz.
-- Palladium . . . . $80.00-$120.00/troy oz.
-- Silver . . . . $3.50-$5.00/troy oz.

Glass:

-- Glass. . . . . $.00 - $.02/lb.

White Paper #6
Cultural and Organizational Issues Related to DFE
by Brad Allenby (AT&T)

DFE practices are designed to be comprehensive, multidisciplinary approaches to integrating environmental concerns and constraints into product and process design procedures. DFE, in fact, marks the transition of the environmental function within firms from overhead to strategic. Accordingly, implementing DFE will require major changes in the organization and culture of many firms. It is characteristic of any organization that it resists changes, a resistance that increases in rough proportion to the magnitude of change demanded. Reducing this resistance is critical for successful implementation of DFE.

The difficulty of implementing DFE can be reduced by, among other things, identifying and facilitating necessary changes, planning an appropriate path for introduction of DFE into the firm, and packaging DFE in familiar design tools. Because DFE is such a new concept, and few firms have even begun the implementation process, there are few hard data regarding how this may be accomplished in practice. Nonetheless, it is at least possible to provide some idea of potential organizational and management changes involved, and steps which may be taken to make these changes easier.

INTRODUCING DFE:

A number of steps can be taken to smooth the introduction of DFE:

- Using the general principles of DFE and all the applicable public material that can be obtained, develop a specialized DFE practice which follows the format of other modules of the firm's product realization process PRP), or design process. The more DFE looks like what you're already doing, the better.

- Similarly, develop an organizational "translation function" which takes environmental data of all kinds and translates it into tools that design teams are already familiar with, such as specifications, checklists, design standards, and standardized components lists. Ideally, designers should not even have to know they are integrating environmental considerations into their design. Whatever you do, don't try to turn your design engineers into environmental professionals: they already have plenty to do.

- Begin the implementation of DFE in small pieces, not by trying to introduce the whole complex, multidisciplinary program at once. Thus, for example, many companies pick a few dimensions of DFE which are particularly relevant to their operations - such as Design for Refurbishment, Design for Disassembly (usually combined with Design for Materials Recycling), and Pollution Prevention - and work on implementing them first.

- In many cases, it may make sense to pick a target subassembly, set of processes, product, or project as a testbed for the application of DFE practices in the firm. This can provide valuable information about the specific barriers to DFE implementation which may exist in your organization. If this is done, however, try to pick something where a degree of success is foreseeable; you need a win, not a failure, to attract followers.

INSTITUTIONAL CHANGES:

Fully implementing DFE will require a number of organizational and management changes. Paying attention to these from the beginning will minimize the barriers such changes pose to implementing DFE in your firm.

- Implementing DFE will require the firm to develop a strategic dimension to its environmental organization. This is a significant change from the "end-of-pipe" orientation environmental organizations have in most firms today. This will in many cases require the development of new competencies in both environmental professionals and existing environmental organizations. The focus of companies' environmental operations will expand from current fixation on compliance, to the linkages between environmental issues and government, consumer, technology and market conditions. Among the jobs these new "strategic" environmental professionals should be expected to perform:

    -- Translate environmental data into "user-friendly" tools for the design team.
    -- Help the company internalize environmental issues, so that they can be better managed (for example, they should identify materials which may be coming under regulatory pressure, such as heavy metals, so that the firm can identify alternatives if possible).
    -- Link with other corporate and business unit organizations, such as public affairs, regulatory affairs, marketing, and business planning groups, to encourage the development of information systems and feedback loops which not only inform product and process design and business planning, but permit the firm to represent its interests to stakeholders, including environmentalists.
    -- Develop software and hardware systems necessary to implement the above functions.

- The firm should establish an accounting system which identifies environmental costs over the lifecycle of products and processes, and allocates them back accurately. Such systems are a significant contrast with current practices, which tend to lump most environmental costs into overhead, where they are “invisible” to managers making production and planning decisions.

- The firm should identify consortia, trade groups and other organizations which can efficiently address precompetitive technical and standards-related issues on a sector or industry basis. This will help create an industry proficiency in DFE which can be a valuable support to individual firm efforts.

CONCLUSION:

The implementation of DFE will be a long, non-trivial process. Based on the experiences of members of the AEA DFE Task Force, firms can anticipate that many of the most difficult barriers will not be technical, but organizational and managerial. These can be overcome, however, by carefully planning the path by which DFE is introduced into the firm, and anticipating and minimizing foreseeable problem areas.

White Paper #7
Design for Maintainability
by E. Thomas Morehouse, Jr. (U.S. Air Force)

The objective of the Design for Maintainability (DF'Mt) component of DFE is to minimize the environmental impacts arising from long term operation and maintenance of products or physical systems. This requires that such impacts be identified and incorporated into relevant process, component, subassembly, and product design activities at the earliest possible stage. It also requires full and accurate information transfer among manufacturers, marketers and consumers to ensure planned reductions in environmental impacts are actually accomplished.

<u>APPLICATION</u>

The DFMt design concept includes a number of operational principles. Components, parts and subassemblies should be replaceable and separately repairable. Moreover, upgrading the product or system as technology advances should not require purchasing of redundant material or assemblies: taken in conjunction with the first principle, this will require modular designs in many cases.

The amount of waste generated as a result of maintenance and repair activities should be minimized through intelligent initial product and system design. Thus, for example, routine maintenance procedures should require only environmentally friendly materials such as biodegradable solvents, as opposed to chlorinated solvents. The frequency of required maintenance activities involving the generation of such waste streams in the first place should be minimized.

Additionally, maintenance waste streams should be reduced by requiring that parts or components should be repairable (and repaired in practice), rather than disposable. Implementing this principle requires that the system elements and the product should be evaluated for reliability, and those component(s) identified as most likely to fail should be addressed as the first priority. Also, each part or component should be removable and refurbishable, rather than being buried in a larger, "throw-away" assembly. Moreover, manufacturers should make arrangements to take back parts replaced by field technicians for refurbishment and reintroduction into commerce, lowering demand for the materials and energy embedded in new parts. An additional benefit of this practice is that manufacturers can see first hand the types of failures that are actually occurring, and incorporate this information in future products, thereby improving quality.

EXAMPLES

- Complex subassemblies that cannot be repaired should be avoided; they increase maintenance costs and generate unnecessary waste when they must be discarded.

- Mechanical parts, such as levers and linkages, should be individually repairable or replaceable.

- Modules should be designed for customer removal and remittance to the manufacturer: refurbished (and upgrade) modules should be customer-installable and economic.

- Products and customer-maintained subsystems should be designed to require the least toxic cleaning and maintenance processes possible, or, better yet, to require no maintenance at all.

- If there are certain maintenance processes which require toxic materials or generate substantial environmental impacts (e.g., potential release of chlorofluorocarbons to the environment), the design and product support systems should encourage performance of those operations only by trained, competent entities. In some cases, this may require the manufacturer to assume those maintenance obligations, or provide close customer support, or assume responsibility for the resultant waste streams.

POTENTIAL PROBLEMS

- Manufacturability, performance, customer specification (e.g., Mil Specs) and/or space constraints may reduce ability to implement DFMt principles. Thus, for example, subassemblies may be too complex to be field repairable, or distribution systems may militate against manufacturers being able to provide close maintenance support.

- Using off-the-shelf components or subassemblies from other suppliers may limit flexibility when implementing DFMt.

- Manufacturers and repair centers may be reluctant to offer small, inexpensive parts as replacement items, in lieu of larger, higher profit subassemblies.

- Labor costs may make refurbishment of complex subassemblies uneconomic.

Manufacturing Life Stages

	Initial production	Secondary processing and manufacturing	Packaging	Transportation	Consumer Use	Reuse/Recycle	Disposal	Summary
Process compatibility								
Materials compatibility								
Component compatibility								
Performance								
Energy consumption								
Resource consumption								
Availability								
Cost								
Environment of Use								

Environmental Life Stages

	Initial production	Secondary processing and manufacturing	Packaging	Transportation	Consumer Use	Reuse/Recycle	Disposal	Summary
Local air impacts								
Water impacts								
Soil impacts								
Ocean impacts								
Atmospheric impacts								
Waste impacts								
Resource consumption								
Ancillary impacts								
Significant externalities								

Toxicity/Exposure
Life Stages

	Initial production	Secondary processing and manufacturing	Packaging	Transportation	Consumer Use	Reuse/Recycle	Disposal	Summary
Community exposure								
Occupational exposure								
Consumer exposure								
Environmental exposure								
Mammalian acute								
Mammalian chronic								
Other acute								
Other chronic								
Bio-accumulative								

Social/Political
Life Stages

	Initial production	Secondary processing and manufacturing	Packaging	Transportation	Consumer Use	Reuse/Recycle	Disposal	Summary
Regulatory status								
Legislative status								
Community impacts								
Labor impacts								
Social impacts								
Significant externalities								

Examining Manufacturing (Sub) Processes

PRODUCTION LINE	
PROCESS DESCRIPTION	

PRODUCTION MACHINERY USED

MACHINE TYPE	IN HOUSE DESIGN? (Y/N)	VENDOR	MODEL NUMBER

MATERIAL/ENERGY INPUT DURING MANUFACTURING OPERATIONS

MATERIAL/ENERGY	CONSUMPTION RATE	REMARKS	COST

MATERIAL OUTPUT DURING MANUFACTURING OPERATION

MATERIAL	OUTPUT RATE	PRODUCT? (Y/N)	IF WASTE, RECYCLABLE? (Y/N)	COST

MATERIAL INPUT/OUTPUT DURING MAINTENANCE/REPAIR

CONSUMABLES/ REPLACEMENT PARTS	USAGE RATE	WASTE? (Y/N)	IF WASTE, RECYCLABLE? (Y/N)	COST
LUBRICANTS, OILS				
CLEANING SUPPLIES				
PROTECTIVE EQUIPMENT				