Design for the Environment (DfE)

What is it and how to do it

Primary goal: SUSTAINABILITY (responsibility toward future generations)

Basic approach: INDUSTRIAL ECOLOGY (imitation of nature)

Imitation of ecosystem: ECO-INDUSTRIAL PARKS (closing material loops, energy efficiency)

In addition: GREEN TECHNOLOGIES (pollution avoidance rather than pollution treatment)

POLLUTION PREVENTION (green processes)

DESIGN FOR ENVIRONMENT (green design)

DESIGN FOR RECYCLING (to promote material loops)

DEMATERIALIZATION (doing with less)
“Design, if it is to be ecologically responsible and socially responsive, must be revolutionary and radical in the truest sense.

It must dedicate itself to nature’s principle of least effort. […]

That means consuming less, using things longer, recycling materials, and probably not wasting paper printing books.”

Victor Papanek, *Design for the Real World*, 1971

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The IMPORTANCE of the DESIGN STAGE:

70% of costs of product development, manufacture and use are decided in early design stages


Examples:

GM truck transmissions: 70% of costs decided at design stage

Rolls Royce: 80% of costs decided at design stage, as determined from an average among 2000 parts

Likewise, it is clear that most decisions that affect future environmental impacts are made at the design stage.
Major design considerations:

Industrial designers need to mind:

- Functionality and performance (product must do the job)
- Manufacturability, logistics (one should be able to make the product)
- Reliability, safety (there must be some quality standard)
- Cost, market penetration (product needs to be competitively priced)
The various levels of DESIGN

**DfM** Design for Manufacturability  So that the product can be made easily and at reasonable cost

**DfL** Design for Logistics  So that all production activities can be well orchestrated

**DfT** Design for Testability  So that the quality of the product may be conveniently checked

**DfP** Design for Pricing  So that the product will sell

**DfSL** Design for Safety & Liability  So that the product is safe to use and the company is not held liable

**DfR** Design for Reliability  So that the product works well

**DfS** Design for Serviceability  So that service after sale can be offered at a reasonable cost to the company

etc. etc.  – to be added:

**DfE** Design for Environment  To reduce or eliminate environmental impacts from cradle to grave

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**Major questions arising in DESIGN FOR ENVIRONMENT**

1. **Product or process?**

   Make the same product in a different way
   
   *ex:* as to minimize energy consumption or generation of by-products

   Make essentially the same product, but with different materials

   Make a different product that fulfills the same function

2. **At which level?**

   **Microscale:** Part of a product
   
   A unit of production

   **Mesoscale:** The entire product
   
   The entire factory

   **Macросcale:** Meeting the function (service) in a new way
   
   Rethinking the industry-environment relation (social concerns)
Redesign of PROCESSES versus redesign of PRODUCTS

Option 1: REDESIGN of PROCESSES

- Many times the only way to approach the redesign (ex. paper, steel)
- Rethink what enters the manufacturing (entry materials)
- Rethink technology of specific processes (ex. solvents)
- Consider what goes out besides the product itself

Barriers: - Technological (alternative is not technically feasible)
- Cost of research and development
- Risk associated with the unknowns
- Corporate inertia ("Don’t mess with success!")

Example of Design for Environment applied to a manufacturing process

Advantages: - Less air to be dust-free and less chance of dust intrusion;
- In the absence of personnel inside the controlled volume, one can also take advantage of an oxygen-free (pure nitrogen) atmosphere to reduce oxidation or other undesirable side effect.
Option 2: REDESIGN of PRODUCTS

- Consider function rather than the object:
  Can this function be met with a smaller product, with a more benign product? 
  Or, at the limit, could it be met as a service without any material product?

- Don’t forget: Package is part of product
  → Rethink the packaging of the product, too

**Barriers:**
- Technological (alternative is not technically feasible)
- Ergonomic, Safety (alternative may be a misfit or unsafe)
- Societal (people may not be prepared for the alternative)
Examples of radical redesigns
(unfortunately having nothing to do with the environment…)

Conventional oven → microwave oven
Wired telephones at home → mobile cell phones
Audiotape player → CD player → iPod
Film camera → Digital camera
Regular “snail” mail → email

Note how in each instance, the function is met by a radically different product, which happens to use less material.

The story of Ray Anderson and Interface, Inc.

Company founded in 1973
From selling carpets to providing a carpeting service
Goal to become a sustainable corporation by 2020

Carpet by the square
Now, let us brainstorm about what goes into

DESIGN for ENVIRONMENT
### The various levels of DESIGN for ENVIRONMENT: DfX

<table>
<thead>
<tr>
<th>DfX</th>
<th>Description</th>
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<tbody>
<tr>
<td>DfM</td>
<td><strong>Design for Manufacturability</strong></td>
</tr>
<tr>
<td></td>
<td>To enable pollution prevention during manufacturing</td>
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<td></td>
<td>For less material</td>
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<td></td>
<td>For fewer different materials</td>
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<td></td>
<td>For safer materials and processes</td>
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<td>DfEE</td>
<td><strong>Design for Energy Efficiency</strong></td>
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<td>For reduced energy demand during use</td>
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<td></td>
<td>For flexible energy use</td>
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<td>Design for use with renewable energy</td>
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<td>Design for Zero Emission</td>
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<td>Design for Carbon Neutrality</td>
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<td>DfZT</td>
<td><strong>Design for Zero Toxics</strong></td>
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<td>DfD</td>
<td><strong>Design for Dematerialization</strong></td>
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<td>DfP</td>
<td><strong>Design for Packaging</strong></td>
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<td></td>
<td>Minimize packaging – Rethink selling method</td>
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<td>DfL</td>
<td><strong>Design for Logistics</strong></td>
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<td></td>
<td>Use of local materials – Less Transportation</td>
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<td>Arrange outsourcing to minimize transportation</td>
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<td>DfL</td>
<td><strong>Design for Longevity</strong></td>
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<td></td>
<td>Design for Modularity</td>
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<td></td>
<td>Design for Serviceability</td>
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<tr>
<td>DfMo</td>
<td><strong>Design for Modularity</strong></td>
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<td></td>
<td>To ease upgrading → Delay replacement</td>
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<td></td>
<td>To ease serviceability and, later, disassembly</td>
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<tr>
<td>DfS</td>
<td><strong>Design for Serviceability</strong></td>
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<tr>
<td></td>
<td>For ease of repairs → longer life</td>
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<td></td>
<td>For recapture of used/broken parts</td>
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<td>DfRM</td>
<td><strong>Design for use of recycled materials</strong></td>
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<tr>
<td>DfRMV</td>
<td><strong>Design for reduced material variety</strong></td>
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<td>DfHM</td>
<td><strong>Design for healthy materials</strong></td>
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<td>DfD</td>
<td><strong>Design for Disassembly</strong></td>
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<tr>
<td></td>
<td>To promote re-use of components</td>
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<td></td>
<td>For quicker and cheaper disassembly</td>
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<td></td>
<td>For more complete disassembly</td>
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<td>For dismantling by simple tools</td>
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<td>DfR</td>
<td><strong>Design for Recycling</strong></td>
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<td></td>
<td>For greater materials recovery</td>
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<td></td>
<td>Use of materials that can be locally recycled</td>
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<td>For easier materials identification</td>
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<td>For safer disposal of non-recyclables</td>
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<td>DfER</td>
<td><strong>Design for Economic Recycling</strong></td>
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<td></td>
<td>To promote recycling</td>
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<td>DfC</td>
<td><strong>Design for Compostability</strong></td>
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<tr>
<td>DfER</td>
<td><strong>Design for Energy Recovery</strong></td>
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<tr>
<td></td>
<td>For safe incineration of residues</td>
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<tr>
<td></td>
<td>For composting of residues</td>
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<tr>
<td>DfC</td>
<td><strong>Design for Compliance</strong></td>
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<tr>
<td></td>
<td>To meet regulations more easily</td>
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<tr>
<td></td>
<td>To prepare for future regulations</td>
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Ideally, one should go beyond designing the product and apply DfE in a broader context, that of

**Environmental Performance**

- by-products and their fate
- processes involved (energy)
- material metabolism in the industry as a whole
- “by-resources” needed during use

But this is a recent line of thought. Little has been done along this line of thinking.

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**Another way of organizing DfE**

1. **Source Reduction**
   - **Objective**: Use less virgin material
   - **Ways**:
     - Modify manufacturing processes to reduce by-products
     - Design products so as to maximize use of recycled materials
     - Design products with less mass
     - Arrange for material reclamation (marketing incentives, networks)
     - Design products with longer life (and add service after the sale)
     - Reduce packaging

2. **Design for Recycling**
   - **Objective**: Facilitate reuse, remanufacture & recycling
   - **Ways**:
     - Labeling of parts, especially plastics
     - Choice of materials (thermoplastics easier to recycle than thermosets)
     - Modify manufacturing processes so that by-products can be recycled
     - Design with less variety of materials

3. **Systems Approach**
   - **Objective**: Find opportunities in the larger scheme of things (knowledge needed here!)
   - **Ways**:
     - Design parts/products so that components contain materials with reuse potential in other industries
     - Life-cycle assessment (LCA), by considering the entire journey of the key materials from first mining to re-incarnation
     - Rethink ways to reach the customer
Smart use of material and modularity

Glass-filled Durethan polyamide-6 resin from Miles Polymers Division, injected on and around a perforated piece of metal, solidifies to cribbed a ribbed, securely bounded, interlocked composite structure.

The Eiffel Tower in Paris, an excellent example of parsimonious use of material.

The Equator EZ 3612CEE is a washer/dryer combination that meets the strict energy efficiency requirements of Energy Star's Tier 4B.

This great little machine is not only two machines in one and compact; it also requires no venting. The 3612CEE offers the perfect solution for apartment dwellers who are unable to vent a standard-type dryer.

The downside of this option is that this type of drying, called condensing, is much slower than a vented dryer. Many users find the best way to do laundry with this machine is to put it in before they go out for the day. It is then completed by the time they return home.

An added benefit is that this machine operates on standard electrical power and does not require 220-volt electrical service like a regular dryer. It does, however, require a water source and a drain.
Minor modifications to the product can also help:

Design approaches that minimize the amount of materials needed to accomplish a desired function: (a) wall thickness transitions (bottom approach preferred); (b) thin design (bottom approach preferred); (c) use of bosses for reinforcement of a thin wall; (d) use of gussets to support a thin curved section; (e) metal inserts on break-off bosses. (Adapted from sketches drawn by J.R. Kirby and J. Wolterra, IBM Corporation.)
LEVELS OF DESIGN FOR ENVIRONMENT

From tinkering at the margin to the social revolution!

Example: Automobile

1. Re-design of parts: Aluminum or plastic radiator cap
   Longer-lasting tires and batteries
   Aluminum or steel engines

2. Re-design of assembly: Eco-friendly painting
   Facilitating disassembly
   Recycling of plastics

3. Re-design of automobile itself: Alternative fuels (ex. ethanol, methanol)
   Alternative powertrains (hybrids, fuel cells)

4. Re-design of transportation systems: Smart highways
   Public transportation

5. Re-thinking the need for mobility: Virtual office (telecommuting)
   Community layout

Deep Design – Deep Ecology

The expression deep ecology, coined in 1973 by the Norwegian philosopher Arne Naess (1912–2009), considers humankind as an integral part of the environment and places more value on other species, ecosystems and processes than is typically allowed by established environmental movements. It leads to a new system of environmental ethics, with a core principle of "biospheric egalitarianism" — the claim that all living things have the same right to live and flourish.

Deep ecologists enunciate several basic principles:

1. All forms of life on Earth have intrinsic value, independent of usefulness.
2. Richness and diversity of life forms contribute to the realization of these values and are also values in themselves.
3. Humans have no right to reduce this richness and diversity except to satisfy vital human needs.
4. The flourishing of human life and cultures is compatible with a substantial decrease of the human population.
5. Present human interference with the nonhuman world is excessive.
6. Policies must therefore be changed. The resulting state of affairs will be deeply different from the present.

etc.
Deep ecologists therefore do not ask:

**How** can we improve this product or activity?

But ask instead:

**Why** do we need this? Can we rather do without?

**Objection:** The collective "we" hardly exists. Society is made of individuals, and very few decisions are made in common. So, the problem is not a lack of will (to resist the bad stuff and seek the good); it is the lack of collective notion.

**Example:** London residents want less road traffic to curtail air pollution, but individually most prefer the convenience of the private automobile.

→ The "Tragedy of the Commons"

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**Business Aspects of Design for Environment**

**POSITIVE ASPECTS:**

- DfRecycling → ease of disassembly → greater serviceability → reduced after-sale costs
- DfRecycling → modularity → several products with identical sub-assemblies
- DfRecycling → modularity → product that can grow with customer’s needs
- Fewer parts → greater reliability → better reputation → more sales
- Source reduction → reduced purchase of materials → reduced costs
  → reduced accidental releases → reduced liability
  → reduced waste → cut in waste-management costs
- Reduction in variety of materials → fewer and bigger orders → lower, bulk rates
- Synergy across company (design, manufacturing & marketing) → quicker response to market changes
- Modular, upgradable products → products that grow with same customer → customer loyalty

**NEGATIVE ASPECTS:**

- Organizational inertia (lack of understanding, fear of cost, "Don’t mess with success")
- Corporate organization (different budgets for different functions → lack of incentives)
- Markets for recycled materials (material captured but no outlet; excessive price volatility)
- Limited databases (in the dark – just don’t know)
- Distraction by small issues (good intention but misdirected)
- Lack of metrics by which success can be measured and decision made (so, management doesn’t buy it)
- Resource limitations
- Government regulations (may force to deal with a problem only a certain way, BACT)
- System inertia increased by interlocking functions
- New processes → Need for new equipment → Capital costs → Obstacle
Note: Movement away from "command and control" regulations to incentives and cooperation.

http://www.epa.gov/dfe/pubs/about/index.htm
Some companies have been established to provide DfE services. Example:

Design for Environment

Kenneth Crow
DRM Associates

There are three requirements of design for the environment: design for environmental manufacturing, design for environmental packaging, and design for disposal and recyclability. Design for environmental packaging involves the following considerations:

- Non-toxic processes & production materials
- Minimum energy utilization
- Minimize emissions
- Minimize waste, scrap & by-products

Design for environmental packaging involves the following considerations:

- Minimization of packaging materials
- Reusable pallets, totes & packaging
- Recyclable packaging materials
- Biodegradable packaging materials

Design for disposal & recyclability involves the following considerations:

- Minimize / reutilization of components & assemblies
- Material selection to enable re-use (e.g., thermoset plastics vs. thermoplastics) and minimize toxicity
- Avoids fillers in plastics such as fiberglass and graphite
- Minimum number of materials / colors to facilitate separating materials and re-use
- Material identification for facilitate re-use
- Design to enable materials to be easily separated
- Design for disassembly (e.g., injection points, fastening vs. bonding)
- Avoid use of adhesives
- Limit contaminants - additives, coatings, metal plating of plastics, etc.
- Maximize use of recyclable or ground material with virgin materials
- Design for serviceability to minimize disposal of non-working products

Design for Environment (DfE) is an engineering perspective which the environmentally related characteristics of a product, process or facility are optimized. Together, HP’s product stewards and product designers identify, prioritize and recommend environmental improvements through a company-wide DfE program. HP’s DfE guidelines derive from involving customer expectations and regulatory requirements, but they are also influenced by the personal commitment of its employees.

The Design for Environment program has three priorities:

- Energy efficiency – reduce the energy needed to manufacture and use our products
- Materials innovations – reduce the amount of materials used in our products and develop materials that have less environmental impact and more value at end-of-life
- Design for recyclability – design equipment that is easier to upgrade and/or recycle
Examples of DfE in manufacturing

**BMW** and **Volkswagen** are both using DfE to study the disassembly and recycling of recovered materials in automobiles. **BMW** has a goal of eventually making automobiles out of 100% reusable and recyclables parts.

**Hewlett Packard** design some of its inkjet printers under a DfE framework. The outer casings include post-consumer plastic from recycled telephones. The modular architecture and use of few permanent screws make the printers easy to disassemble for repair or recycling. Any plastic larger than 3 grams is identified and marked by type. Components of the printer are molded using a thin-walled process so less material is needed. Power down and sleep modes means 50% less energy is used by these printers than comparable inkjet printers.

**Sun Microsystems** has included a variety of disassembly features and post consumer plastics in their products following the implementation of a DfE program. Heavy metals have also been eliminated from plastics, packaging, inks and manuals used in Sun products.

**IBM** has incorporated numerous design for environment features in a series of computer products, including on/off power programming, powder coatings, labeling of plastic parts, and a new method for attaching acoustic foam that facilitates removal for recycling. IBM also uses recycled plastics in many product lines. Plastic parts are kept free of contamination from labels and paint so that they stay recyclable. Some products are designed to be upgradable so that the equipment does not have to be replaced for improved performance.