Primary goal:

**SUSTAINABILITY**
(responsibility toward future generations)

In addition:

**GREEN TECHNOLOGIES**
(pollution avoidance rather than pollution treatment)

**DESIGN FOR ENVIRONMENT**
(green design)

**DESIGN FOR RECYCLING**
(to promote material loops)

**DEMATERALIZATION**
(doing with less)

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**THE IMPORTANCE OF DESIGN:**

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
The various elements of DESIGN

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

**DIL**  Design for Logistics  So that all production activities are well orchestrated

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

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

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

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

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

etc. etc.

Now to be added:

**DIE**  Design for Environment  To reduce or eliminate environmental impacts from cradle to grave
The various sub-levels of DESIGN for ENVIRONMENT:

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
<th>Benefits</th>
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<tbody>
<tr>
<td>DfMa</td>
<td>Design for Manufacturability</td>
<td>To enable pollution prevention during manufacturing</td>
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<tr>
<td></td>
<td></td>
<td>For less material</td>
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<tr>
<td></td>
<td></td>
<td>For fewer different materials</td>
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<td></td>
<td></td>
<td>For safer materials and processes</td>
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<tr>
<td>DfEE</td>
<td>Design for Energy Efficiency</td>
<td>For reduced energy consumption during production</td>
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<td>For reduced energy demand during use</td>
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<td></td>
<td></td>
<td>For flexible energy use</td>
</tr>
<tr>
<td>DfSe</td>
<td>Design for Serviceability</td>
<td>For ease of repairs → longer life</td>
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<tr>
<td></td>
<td></td>
<td>For recapture of used/broken parts</td>
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<tr>
<td>DfMo</td>
<td>Design for Modularity</td>
<td>To ease upgrading → Delay replacement</td>
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<tr>
<td></td>
<td></td>
<td>To ease serviceability</td>
</tr>
<tr>
<td>DfD</td>
<td>Design for Disassembly</td>
<td>To promote re-use of components</td>
</tr>
<tr>
<td></td>
<td></td>
<td>For quicker, cheaper and more complete disassembly</td>
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<tr>
<td>DfR</td>
<td>Design for Recycling</td>
<td>For greater materials recovery</td>
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<tr>
<td></td>
<td></td>
<td>For easier materials identification</td>
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<tr>
<td></td>
<td></td>
<td>For safer disposal of non-recyclables</td>
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<tr>
<td>DfER</td>
<td>Design for Energy Recovery</td>
<td>For composting of organic residues</td>
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<td></td>
<td></td>
<td>For safe incineration of residues</td>
</tr>
<tr>
<td>DfC</td>
<td>Design for Compliance</td>
<td>To meet regulations more easily</td>
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<tr>
<td></td>
<td></td>
<td>To prepare for future regulations</td>
</tr>
</tbody>
</table>

Considerations in DESIGN for ENVIRONMENT

1. Product or process?

Make the same product in a different way
ex: minimize generation of by-products, use recycled materials in production

Make essentially the same product, but with different materials
ex: switch from metal to plastic for several parts, combine functions into fewer parts

Make a different product that fulfills the same function
ex: microwave oven replacing conventional oven

2. At which level?

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

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

** Macroscale:** Meeting the function (service) in a new way
Rethinking the industry-environment relation (social concerns)
**Approaches**

**PROCESSES**

Rethink the way the product is made
Many times the only way to approach the redesign (ex. paper, steel)
Rethink what enters the manufacturing (input materials, needed machinery)
Rethink technology of specific processes (ex. solvents, adhesive labels vs. engraving)
Consider what goes out besides the product itself (by-products or waste?)

*Barriers:* - Technological (alternative is not technically feasible)
- Cost of research and development (R&D)
- Risk associated with the unknowns – apprehension, fear
- Corporate inertia (“Don't mess with success!”)

**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?

Do not forget to also rethink the packaging of the product.

*Barriers:* - Technological (alternative is not always technically feasible)
- Ergonomic, Safety (alternative may be too small or unsafe)
- Societal (people may not be prepared to accept the alternative)

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**Design for Environment**

**Process changes**
- Improved operating practices
  - Better maintenance
  - Efficient management
  - Stream segregation
  - Material handling
  - Inventory control
  - Employee training

**Product changes**
- Changes in materials
  - Material purification
  - Less material variety
  - Avoidance of toxics
  - Generation of more benign by-products

**Technology changes**
- Layout changes
- Increased automation
- Improved equipment
- Energy-efficient machinery

**Amount of material**
- Consolidate parts
- Smaller size

**Assembly**
- Design for service
- Design for disassembly

**From product to service**
- Sales → service
- Toward complete dematerialization
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.

Disadvantages: - Major R&D cost and time delay
- Huge capital cost
- Need for technicians trained differently.

British example of a product designed for the environment

Teapot designed for disassembly by Polymer Solutions, Inc. for British Kettles, Ltd. (Courtesy of Fitch, Inc, Columbus, Ohio. also in Industrial Ecology, by T. Graedel & B. Allenby, 1995)
Robomow RL2000 Automatic Lawn Mower with Base Station

Price: $2,221.00

Robomow® RL2000 is an automatic lawnmower that cuts the grass all by itself.

All you have to do is schedule a weekly program. It will depart from the base station at the pre-set scheduled days and times. At the end of each operation Robomow® returns to the base station for charging until the next scheduled operation. Your lawn will be maintained even when you are away from home!

The RL2000 is recommended for lawns of up to 1,500 - 2,000 m² (4,921 - 6,561 ft²) depending on grass type and condition.

- 53cm heavy-duty 3-blade mulching system
- Exclusive drop-and-go 24-volt batteries
- User controlled theft protection and disabling system
- Manual controller to mow very narrow areas manually
- Knobby wheels: recommended for lawns with high grass, sloping or bumpy ground
- Top of the range model and is designed to mow big domestic lawns.
XEROX:  
Parts Reuse and Equipment Remanufacturing

The story of Ray Anderson and Interface, Inc.

Company founded in 1973
Aims to become a sustainable corporation by 2020

Ray C. Anderson, Founder, Chairman and CEO of Interface, Inc.

Carpet by the square
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 (ex. hybrids, electric, fuel cells)
   - Automatic piloting cars

4. Re-design of transportation systems: 
   - Bike lanes
   - Public transportation

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

Toward shallow redesign

Toward deep ecology