Introduction to Green Design

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1. Introduction

"**Green design**" is intended to develop more environmentally benign products and processes. The application of green design involves a particular framework for considering environmental issues, the application of relevant analysis and synthesis methods, and a challenge to traditional procedures for design and manufacturing.

In many past situations, environmental effects were ignored during the design stage for new products and processes. Hazardous wastes were dumped in the most convenient fashion possible, ignoring possible environmental damage. Inefficient energy use resulted in high operating costs. Waste was common in material production, manufacturing and distribution. Consumers cast aside products, usually with only minimal re-manufacturing or recycling.

Recognition of these problems inspired environmental engineering applications to clean up past pollution (called remediation) and ongoing waste streams (called waste treatment). Clean ups are still needed in many cases. But design changes can often be more effective at reducing environmental burdens and more efficient at reducing costs than traditional "end-of-the-pipe" clean up strategies. Some examples of such practices include:

- **Solvent substitution** in which single use of a toxic solvent is replaced with a more benign alternative, such as biodegradable solvents or non-toxic solvents. Water based solvents are preferable to organic based solvents.

- **Technology change** such as more energy efficient semi-conductors or motor vehicle engines. For example, the Energy Star program specifies maximum energy consumption standards for computers, printers and other electronic devices. Products in compliance can be labeled with the "Energy Star." Similarly, "Green Lights" is a program that seeks more light from less electricity.

- **Recycling of toxic wastes** can avoid dissipation of the materials into the environment and avoid new production. For example, rechargeable nickel-cadmium batteries can be recycled to recover both cadmium and nickel for other uses. Inmetco Corporation in Pennsylvania and Accurec in West Germany are routinely recycling such batteries using pyrometallurgical distillation.

The challenge of green design is to alter conventional design and manufacturing procedures to incorporate environmental considerations systematically and effectively. This requires change in these existing procedures. Change for any existing process is difficult. Changing design procedures is particularly difficult because designers face many conflicting objectives, uncertainties, and a work environment demanding speed and cost effectiveness. Environmental concerns must be introduced in practical and meaningful fashions into these complicated design processes. For the future, we wish to prepare consumers and designers to think proactively about the environment.

2. **Objectives for Green Design**

There is no widespread consensus or agreement on the particular goals to be pursued by green design. Some argue that green design and pollution prevention should be pursued solely to reduce costs. In this view, any waste from a process or product is an opportunity. Others focus on particular strategies, such as recycling to save raw materials, and develop goals specifically for these strategies. Another approach is to direct all attention to a particular environmental problem, such as global warming, or a particular media, such as air pollution, and ignore other environmental effects.

Each of these approaches is flawed. Some pollution prevention may be socially desirable but might not be economical for the industry involved to stop. Some recycling may have environmental burdens larger than the savings, especially if long distance transport is involved. Focusing upon a single issue, such as air pollution, may result in transfer of pollution to another media such as water. We need a more general approach.

The social goals for green design relate to ensuring a sustainable future for our society, in regard to both resources and ecological health. In one view, a sustainable future will result from the continuing development of technology and knowledge, so that future generations can overcome any environmental problems caused now. However, there is no certainty that the requisite technology and knowledge will develop sufficiently quickly, especially with predicted sizable worldwide population increases. Avoiding harm to the environment is ultimately a question of individual and collective ethical judgements on the proper role of humans in their global environment.

We can advance three general goals for green design in pursuit of a sustainable future:

- Reduce or minimize the use of non-renewable resources
- Manage renewable resources to insure sustainability; and
- Reduce, with the ultimate goal of eliminating, toxic and otherwise harmful emissions to the environment, including emissions contributing to global warming.

The objective of green design is to pursue these goals in the most cost-effective fashion.

With these three overarching goals, specific objectives can be defined and pursued. For example, more energy efficient devices can reduce the use of non-renewable resources and toxic emissions, as long as the energy efficient changes do not have excessive environmental burdens. Thus, building insulation may save heating but entails some environmental costs from manufacture and installation.

A green product or process is not defined in any absolute sense, but only in comparison with other alternatives of similar function. For example, a product could be entirely made of renewable materials, use renewable energy, and decay completely at the end of its life. However, this product would not be green if, for example, a substitute product uses fewer resources during production and use, or results in the release of fewer hazardous materials. Other things being equal, a car that gets 50 miles per gallon is greener than one that gets 30 miles per gallon— unless the owner family cannot fit into the more fuel efficient car necessitating two trips. A fully loaded bus is greener than either car, but a bus with one passenger is not at all green.

Rarely is one product greener in every dimension (resource and energy use, emissions, reyclability etc.) than other products; there are usually tradeoffs among characteristics. For example, making cars more fuel-efficient requires making them lighter. This can be accomplished by substituting aluminum or plastic for steel. Both aluminum and plastic require more energy during production than does steel. How should we compare the energy required during production with the energy required for operation? One approach is to calculate how many miles the car must go to “pay back” the energy required during production. Another example is that some new materials and composites, such as carbon fibers, have many advantages, but cannot be recycled. Which is more important, the ability to recycle or the lighter weight and strength? Finally, if petroleum is in extremely short supply, saving gasoline may be desirable even if the result is increasing total energy use, e.g., cars powered by methanol from coal.

Developing and marketing green products is a concrete step towards sensible resource use and environmental protection and towards sustainable economic development. Green products imply more efficient resource use, reduced emissions, and reduced waste, lowering the social cost of pollution control and environmental protection. Greener products promise greater profits to companies by reducing costs (reduced material requirements, reduced disposal fees, and reduced environmental cleanup fees), and raising revenues through greater sales and exports. Designing green products offers much to the current generation, as well as providing future generations with a planet that will enable them to survive and prosper.

Governments, particularly in Europe, have been providing incentives for greener product development. As examples, Germany’s product takeback laws have prompted European and U.S. Industries to reduce packaging and start designing products with disassembly and recycling in mind. France and The Netherlands have special government agencies to foster clean technologies. In the US, many government purchasing criteria specify the use of recycled materials; the federal government has ordered its employees to look for recycled products and has initiated a number of energy efficiency programs for products and buildings. Toxic emissions have been voluntarily reduced in many industries, in part due to the scrutiny provided by toxic emission reporting requirements. Significant progress has already been made as companies see that they can lower costs and increase revenues by making green products or introducing green processes. Consumers have been slower to respond to green products. In the end, progress is limited by what consumers are willing to purchase.

3. **Systems Thinking**

A central concept in green design is the notion that the systems effects of design decisions should be considered. In designing a new product, the environmental burdens associated with material supply, manufacture, use and disposal may all be relevant. For example, a 50-mile per gallon car whose components can be recycled easily is relatively green. However, as a means of getting from one place to another, it is much less green than a bicycle, even if the bicycle is made of materials that cannot be reused or recycled. A community where people can walk to work, school, and shopping is inherently greener than cities such as Los Angeles and Dallas where an automobile is required to get to work, shopping districts, schools and recreation areas. Thus, while one product is greener than another is, the more important attribute has to do with the system in which each product is used.

Some specific approaches to such systems thinking include:

Environmental Life Cycle Assessment (LCA) is a technique for tracing out all the environmental effects and resource needs of a new product or process through the material suppliers, through manufacture, use and disposal. It is intended to provide a comprehensive assessment of environmental effects. For reasons of lack of data, complexity of analysis and uncertainty, life cycle assessments often draw arbitrary boundaries (to eliminate all possible suppliers) and stop at the stage of just producing an inventory of emissions and resources rather than proceeding to assessment and improvement.

Material Flows and Cycles is a technique for tracing material use and location over time. For example, steel is routinely recovered from products such as automobiles, melted and re-used in a closed recycle loop. Some materials are disposed of into landfills, although the material may sometime in the future be recovered and re-used**.** Materials can move between the anthroposphere (the manmade environment) and the natural environment In recycling materials, there is a distinction between closed-loop (re-use for the same function) and open loop (re-use in a different function, typically with lower quality requirements). In tracing materials flows, it is important to be clear about the boundaries of analysis and the uncertainty of mass measurements.

4. Engineering Design

Design is a complicated messy process. Designers are faced with numerous competing requirements and constraints. For example, a personal computer must be fast and powerful and cheap. To be green it must also be energy efficient, and easily recycled. Designers have struggled to achieve the first set of attributes. Achieving environmental goals makes the task more difficult. For most consumers, energy efficiency and recyclability are less important product attributes, which means that designers cannot compromise other product attributes in becoming green.

Designing and manufacturing green products requires appropriate knowledge, tools, production methods, and incentives. Aids for green design must be easy and quick to use and understand. Ideally, these design tools will help identify design changes that have lower costs while improving materials use and recyclability. For example, using snap fits rather than metal fasteners may have little additional cost burden at the design stage but may significantly increase recycling potential.

5. Some Green Design Methods and Tools

Mass balance analysis involves tracing the materials or energy in and out of an analysis area such as a manufacturing station, a plant or a watershed. Ideally, mass balances are based on measurements of inflows, inventories, and outflows (including products, wastes and emissions). In actuality, all the data needed is rarely available or even consistent.

Green Indices: How can an analyst compare a pound of mercury dumped into the environment with a pound of dioxin? Green indices or ranking systems attempt to summarize various environmental impacts into a simple scale. The designer or decision-maker can then compare the green score of alternatives (materials, processes, etc.) and choose the one with the minimal environmental impact. This would contribute to products with reduced environmental impacts. For example, Volvo’s Environmental Priority Strategies System (EPS - this involves calculating “environmental load units” of alternatives). Although none of these tools is yet capable of incorporating many different types of environmental impact, all provide at least rudimentary guidance to the designer in choosing materials, components, or process alternatives that have reduced environmental impacts.

Design for disassembly and recycling aids Design for disassembly and recycling (DFD/R) means making products that can be taken apart easily for subsequent recycling and parts reuse. For example, Kodak's 'disposal' cameras snap apart, allowing 87% of the parts (by weight) to be reused or recycled. Unfortunately, the economic costs associated with physically taking apart products to get at valuable components and materials often exceeds the value of the materials. Reducing the time (and thus cost) of disassembly might reverse this balance. Thus DFD/R acts as a driver for recycling and reuse. DFD/R software tools generally calculate potential disassembly pathways, point out the fastest pathway, and reveal obstacles to disassembly that can be "designed out".

Risk analysis is a means for tracing through the chances of different effects occurring. For example, the risk of toxic emissions is estimated by estimating the amount and type of emissions, the transport in the environment, the ecological and human exposure, and the likely damage. All of these analysis steps are likely to be uncertain. Risk is a useful concept for integrating effects over several media (such as air, water and land). However, we have difficulty judging and measuring risk particularly for low risk/high consequence actions.

Material selection and label advisors Any of several materials can produce a particular quality component or product. However, they have different environmental implications. Material selection guidelines attempt to guide designers towards the environmentally preferred material. For example, Graedel and Allenby [1995] present the following guiding principles for materials selection:

- Choose abundant, non-toxic materials where possible.
- Choose materials familiar to nature (e.g. cellulose), rather than man-made materials (e.g. chlorinated aromatics).
- Minimize the number of materials used in a product or process.
- Try to use materials that have an existing recycling infrastructure.
- Use recycled materials where possible.

In addition to these generic guidelines, companies such as IBM and Chrysler have been developing and using specific materials selection guidelines for environmentally-sound product development which describe in detail the materials that should be used for specific applications. Label advisors are generally marks on materials or products that reveal information about the material content relevant to materials handling and waste management. For example, the plastic bottles used in many consumer products usually have a plastic identification symbol that can be used in plastics resorting and recycling efforts. Even labels are subject to green design. Embedding labels into a material is preferable to a separate label material attached with an adhesive.

Full cost accounting methodologies. Many corporations and consumers want to support green products and sustainability but do not know how to make greener decisions. Designers and plant managers are specialists who cannot be expected to be environmental experts capable of estimating the environmental and sustainability implications of their decisions. As a result, a company often incurs high costs from using a material or process that creates environmental problems when an environmentally benign material or process exists. Often consumers purchase products that create environmental problems because they do not know about green alternatives. Companies need management information systems that reveal the cost to the company of decisions about materials, products, and manufacturing processes. This sort of system is called a "full cost accounting" system. For example, when an engineer is choosing between protecting a bolt from corrosion by plating it with cadmium versus choosing a stainless steel bolt, a full cost accounting system could provide information about the purchase price of the two bolts and the

additional costs to the company of choosing a toxic material such as cadmium. In many cases, the choices that a designer or consumer makes also impose costs on society. For example, choosing a cadmium coating increases the possibility of human exposure to a toxic substance. The designer and consumer might be informed by showing them this social cost of the cadmium, i.e., the cost of preventing the exposure and the potential health risks of exposure. This information might be communicated by having a "social" cost listed on the price tag. A still stronger step would be to actually charge the designer and consumer for the social costs of environmentally damaging materials or products. Thus, the government might add an environmental tax or effluent fee that would account for the social damage.
A number of companies are beginning to launch preliminary full cost accounting efforts in order to spotlight products that result in relatively large environmental costs.

6. **Glossary**

Green Design is the attempt to make new products and processes more environmentally benign by making changes in the design phase.

Design for the Environment (DfE) or EcoDesign. These terms are used interchangeably for Green Design in practice.

Industrial Ecology is a systems view of the manmade environment in which activities are managed so as to optimize resource, energy and capital use for sustainable development.

Life Cycle Assessment is a systematic analysis of the environmental effects of a new product or process. A traditional LCA consists of i) defining a system boundary, ii) carrying out an inventory of all the materials and energy used and all the environmental discharges resulting from the product's manufacture, use, and disposal within the defined boundary, iii) carrying out an assessment of the environmental implications resulting from the discharges and materials use identified in the inventory, and finally, iv) carrying out an assessment of the opportunities for improvement.

Pollution Prevention is a subset of green design intended to change processes so as to reduce waste and toxic emissions.

Product takeback laws: Laws in some European nations that transfer the responsibility of packaging and product disposal from the consumer to the producer. For example, in Germany, manufacturers are responsible for ensuring that packaging is recycled appropriately, and recent laws also require manufacturers to certain products to recover and recycle their products when the consumer no longer needs the product.

Sustainable Economic Development: Defined by WCED [WCED, 1987] as "meeting the needs of the present without compromising the ability of future generations to meet their needs". For example, a vehicle powered by solar radiation would be sustainable at least in terms of energy for operation. Power generated from wind, water and sunlight are commonly viewed as preferable to combustion of fossil fuel.

7. Further Reading

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3. Office of Technology Assessment, “Green Products by Design,” US Congress, OTA-E-541, Washington, DC, 1992.
4. World Commission on Environment and Development (WCED), 1987. Our Common Future. Oxford University Press.

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