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PRODUCT LIFE CYCLE: THE ULTIMATE AIM IN PRODUCT DEVELOPMENT

M. Hundal

Department of Mechanical Engineering
The University of Vermont
e-mail: hundal@emba.uvm.edu

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Abstract: *Product cost is one of the key attributes considered during the development process. The customer is interested not just in the purchase price but indeed in the total costs during the product's life. The life cycle costs include initial cost, operating and maintenance costs, less any salvage value. With increasing environmental awareness, the disposal cost can also become a significant part of the total cost. The paper addresses the point that the whole life cycle including the environmental aspects be considered during the product development process. Several examples are shown to illustrate that products and processes can be made environmentally friendly and cost competitive at the same time. Review of literature is presented.*

1. PRODUCT DEVELOPMENT AND COSTS

Traditionally, the key ingredients in a manufacturing company's economic viability are (1) product innovation, and (2) quickly developing and bringing products to market. The highly competitive nature of the marketplace requires that manufacturers be able to bring products to the customer, with the following attributes: (a) Be of high quality, (b) be delivered in short time, and (c) be of low cost [1]. Product development consists of four steps: Product Planning, Design, Process Planning and Manufacturing. We look here at cost as the key development attribute. In each of the product development activities costs are incurred. These and how they are governed by the different activities is shown in Figure 1 [2].

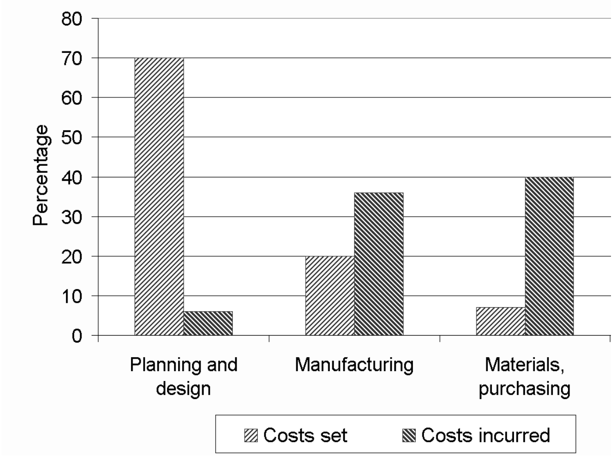

Fig. 1. *Costs set and incurred in different activities*

It is obvious that the planning/design phases constitute the smallest portion of the total cost, yet have the greatest influence on it. This stems from the fact that most of the decisions regarding the downstream stages of the product are made at these stages. The distribution of the total costs of a product during its life cycle vary according to the type of product. Figure 2 shows such a breakdown for three types of products [3].

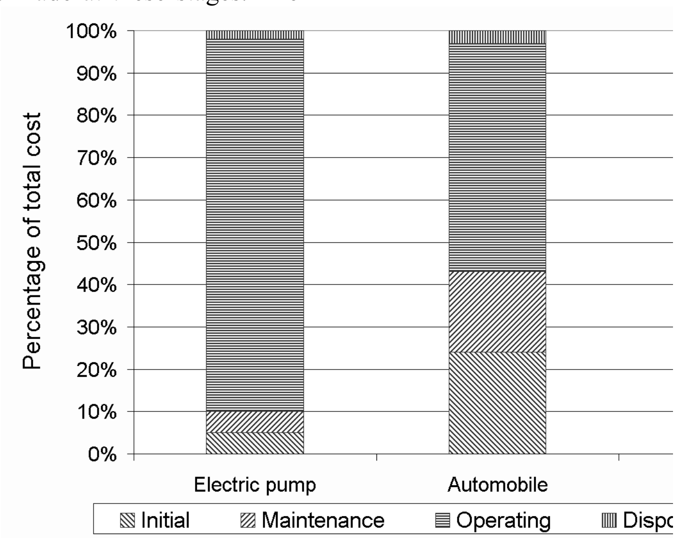

Fig. 2. *Cost breakdown for different life phases*

As shown here, a simple tool's costs comprise only of the initial and disposal costs; an automobile has significant operating and maintenance cost, whereas a device such as an electric motor driven pump has the operating cost as the largest portion of its total costs. This figure also shows where the greatest cost reductions are most likely to be achieved. Operating and maintenance costs are, of course, time-dependent.

2. LIFE CYCLE ENGINEERING

As the environmental concerns have become more important to the society, and thus eventually to companies, the environmental impact of products need to be taken into account in the product development process [4]. In the final analysis, companies are concerned with product costs. It is generally (and falsely) believed that environmental requirements lead to higher costs. Several examples are cited here, that show where companies have applied innovation to both the product and the process to achieve both an improved product, as well as a `greener' image, which lead to market advantages.

2.1. Definitions

Design for Environment (DFE) is one of the design aims. It is one type of `Design for X', where X may stand for M (manufacturability), C (cost), A (assembly), etc. DFE aims to integrate environmental requirements in the design process. It thus seeks to minimize the environmental impacts of the product at each stage of its life cycle. The word `design' used here and elsewhere, is often used to describe the total Product Development Process (PDP).

Eco-design/ecological Design is a term often used in European literature. It implies environmentally friendly design, i.e., low environmental burdens and combines the ideas of Design for Environment and Life Cycle Design. Green Design is a term also used to denote environmentally friendly design, i.e., creating low environmental burdens.

Life Cycle (LC) of a product begins with material extraction and proceeds through material processing, manufacturing, use and its ultimate disposal (Figure 3). Each of these activities is referred to as a life stage or phase. The term is generally qualified by a noun which indicates which aspect of the life cycle is addressed: A = Assessment; D = Design; E = Engineering; I = Inventory, etc.

Life Cycle Assessment (LCA) is a method for assessing the environmental impact of a product over its life cycle, i.e., at each of its life stages. Life Cycle Design (LCD) is a design methodology which considers all life stages of a product. Many authors regard LCD and DFE to be interchangeable terms. DFE may be regarded as one of the aims of LCD.

Life Cycle Engineering (LCE) is concerned with the total product life, from raw material acquisition, through material processing, manufacturing, use and disposal. The aims of LCE may differ, e.g., low cost, long life span, minimizing resource use, etc.

Product Development Process consists of the steps of Product Planning, Design, Process Planning, through Manufacturing. The term `product design' is often used to indicate the complete PDP, although it is only one of the steps in the process. The two approaches - DFE and LCE - have come to mean the same things. Once we begin to look at the complete life cycle of the product, the environmental impacts become important as a matter of course.

2.2. Materials Flow

Figure 3 shows the materials flow in the different life phases of a product [4]. Not shown is the fact that in each phase energy is required and waste is produced.

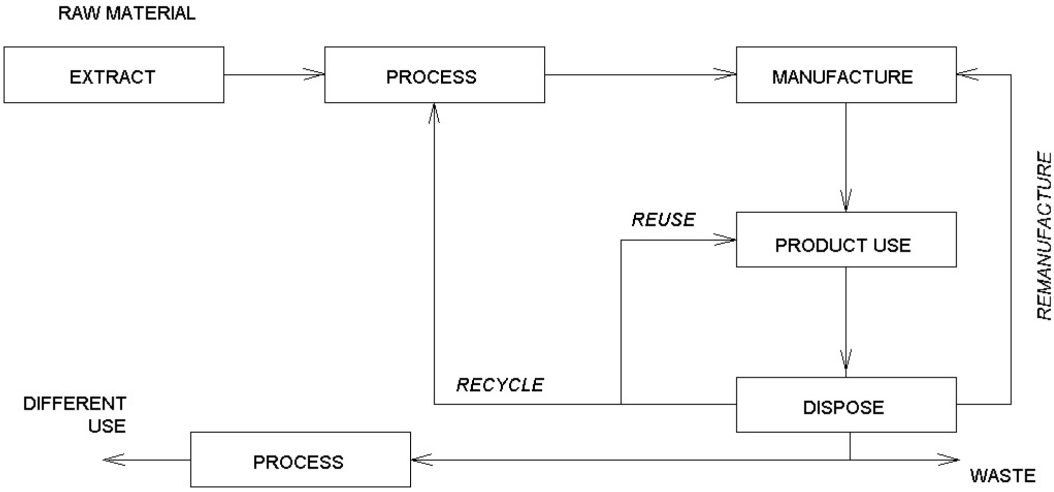

Fig. 3. *Life phases of a product*

Figure 3 also shows how the terms *reuse*, *remanufacture* and *recycle* are applied. In the order of preference, a product (or its subassemblies, parts, etc.) should be reused. Failing that it can be remanufactured and put back into service. The next preferable step it to recycle by way of reprocessing the materials. The figure also shows that parts of a product may be put to a different use. The least desirable alternative is the generation of waste, which would end up in a landfill. Goals of life cycle engineering may be summarized into `reduce environmental burdens' and `find sustainable solutions.' The environmental burdens consist of resource depletion (e.g., energy and materials), ecological effects and human health effects. A product generates environmental burdens at each of its life stages. Different types of product generate varying amounts of burden in the different life stages. Figures 4 [5] and 5 [6] show just a small part of the problem facing the world.

Figure 4 shows the generation of municipal solid waste per capita for some of the developed countries. In nearly all of the countries there has been an increase in solid waste generation over time. There is notable disparity between certain countries with comparable standards of living. There is a potential dependency of waste production in a country to resource consumption and the efficiency of resource use.

Some of the literature on the life cycle will be discussed next.

Conway-Schempf and Hendrickson [7] present an overview of the LCA, provide definitions, a historical perspective, stages of LCA and LCA methods. Two case studies show the effects of use of alternate materials: paper vs. Styrofoam cups and asphalt vs. concrete. Caudill, et al, [8] provide an extension on the LCA method (Multi-lifecycle Assessment - MLCA) by focusing more on quantifying materials, energy and environmental burdens associated with end-of-life options and on value of returning parts and materials back in use, through process modeling and understanding of demanufacturing, reengineering and remanufacturing. The MLCA software is presented as a tool is developed for analyzing and comparing the environmental impacts, energy consuming, and cost of different products. The software includes interfaces for the lifecycle stages of material processing, production, packaging and distribution, use, demanufacturing, reengineering and remanufacturing.

Sullivan [9] discusses Life Cycle Assessment in depth, in SETAC framework, including Life Cycle Inventory, Life Cycle Impact Assessment and Life Cycle Improvement/ Interpretation. He also presents other approaches to LCA, viz., EPS, Eco-Indicator 95 Method and Threshold Inventory Interpretation Method (TIIM). He shows applications of LCA to the production of aluminum, for comparing powertrain castings of aluminum and magnesium, in the automobile industry and a comparison of three fruit-juice containers by using TIIM.

Life cycle assessment of non-ferrous metals, with an application to zinc production is presented by Gediga, et al [10]. They emphasize the effect of different technologies and different geographic locations on life cycle inventory. Data on primary energy consumption and SO_2 emissions for selected alloys and alloying elements are presented. The LCA of zinc production is given for two processes: electrolysis and smelting, and the resulting environmental profiles are compared. The environmental impacts considered are primary energy demand, global warming potential and heavy metals emissions.

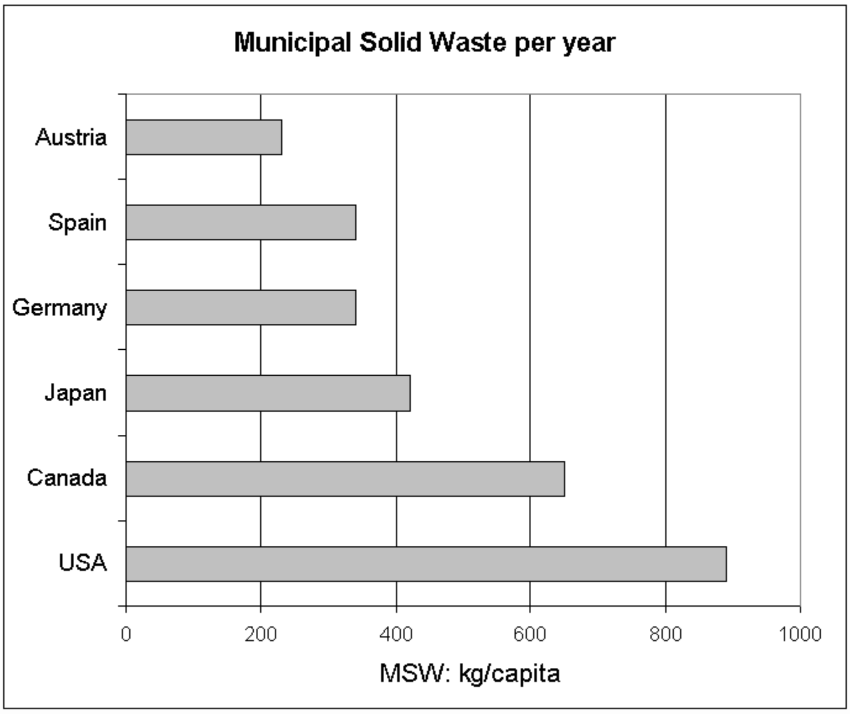

Fig. 4. *Worldwide generation of municipal solid waste*

Caudill, et al [11] report on a computer-based simulation and modeling of de-manufacturing systems. The software is intended to evaluate the operation of de-manufacturing facilities for electronic products. A typical de-manufacturing system consists of inspection of collected products, staging of the workflow, disassembly of products, shredding of products or components, separation into bins and shipment of the recovered materials and components for further processing or use. the output of the software includes system throughput, resource/worker utilization, bottleneck identification, hazardous-material/recyclable/solid-waste output characteristics and cost and profit assessment. The software is intended to be an alternative to commercially available simulation software from the point of view of simplicity and thus requiring less training for its use.

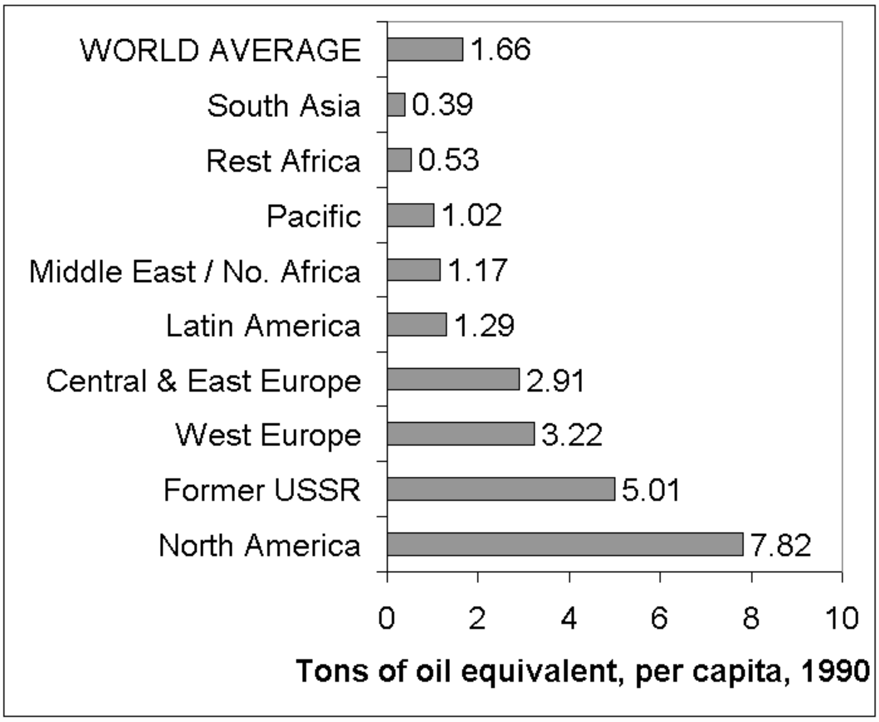

Fig. 5 *Energy demand per capita*

Figure 5 shows energy use per capita for different parts of the world. The disparity between the industrialized and developing nations is evident from this chart.

2.3. Applications of Eco-design

The application of eco-design in the electronics industry is described by Stevels [12]. General characteristics of environmental approaches are divided into the defensive, cost-oriented and the proactive approaches. The characteristics include the drivers, objectives, core processes, control, etc. Examples pertinent to each of the three approaches are given. The author cites results for his company, Philips Consumer Electronics. The defensive approach creates awareness of the problem, environmental management becomes a priority, environmental information is collected, etc. The cost-oriented approach has the advantages of showing that saving energy, reducing packaging, by building upstream and downstream networks, etc can reduce costs. The proactive approach helps by integrating environment into business, thus setting vision and strategy, looking for broad-based solutions, etc.

Johnson and Wang [13] discuss the economics of disassembly of products for material recovery. The recovery process, disassembly sequence, choice of components recovered and design characteristics for ease of disassembly are dealt with in detail. Recent research contributions are summarized. The authors present economic models of disassembly which take into consideration the option of recovery, present disposal cost and the costs of disposal and disassembly. The authors define ``disassemblability" as the ability to optimize the design and disassembly process for removal of specific parts or materials in a manner which will simultaneously minimize costs and maximize the material value to be reclaimed.

3. STRATEGIES FOR REDUCING COSTS WHILE REDUCING ENVIRONMENTAL BURDENS

It appears to be a common belief in the society, and particularly in the industrial sector, that reducing pollution, making products and processes more environmentally friendly increases the costs. Studies have shown, as quoted by Porter and van der Linde [14], that this is not always the case. A company or industry which incorporates the environmental requirements in its product innovation process stands to gain and become an industry leader. Some of the examples cited are given below. For example, in printed circuit board industry, 33 major process changes were initiated, of which 13 came from pollution control personnel. Of the latter:

- 12 changes resulted in cost reduction.
- 8 changes resulted in quality improvements.
- 5 changes resulted in extension of production capabilities.

3.1. Waste Prevention

A study of waste prevention in chemical plants, motivated by waste disposal costs and environmental regulation, found that innovations resulted in increased resource productivity:

- Of the 181 waste prevention activities, only one resulted in cost increase.
- Of the 70 activities which led to changes in product yield, 68 were increases in the yield. Average increase was 7%.
- Of the 48 initiatives for which capital cost information was available, one-quarter required no capital investment.
- Of the 38 initiatives for which payback data was available, two-thirds had a payback period of six months or less.
- For each dollar spent on source reduction, an annual savings of $3.49 was reported.

Companies must look at pollution as a waste of resources. Within the company, packaging represents material waste and poor process controls. Often a company does not even know how many waste streams there are. Outside the company, packaging has to be discarded by people down the supply chain: wholesalers, distributors and customers. This represents wasted effort and energy, thus adding to the costs. Likewise, customers should not have to put up with polluting products.

3.2. Role of Innovation

A manufacturer has four inputs, or resources, to put into the enterprise. These are *raw material*, *energy*, *labor* and *capital*. In the past a company with access to cheap inputs had a marketplace advantage. With the globalization of the economy, no single company, or indeed a country, has a lock on cheap resources. A company from a high-cost country can build a plant in a low-cost country. Rather, today, it is how a company uses its resources that make it competitive. Porter and van der Linde [14] call this ‘‘resource productivity.’’

A competitive product is one that (a) can be produced cheaper than similar products, or, (b) one which provides more value, for which customers are willing to pay more. Competitiveness and environmental friendliness are not mutually exclusive. Through innovation, by making better use of resources, products can be made more competitive and environmentally friendly.

As environmental awareness has grown worldwide, customers are more willing to pay higher prices for ‘‘green’’ products. Companies which have innovated to be the first-in-the-marketplace with new or improved products, enjoy advantages by being the leaders. By early introduction a product has a marketplace advantage by gaining early customers who lock on to it, develop loyalty and are less likely to switch [1]. Germany adopted stricter environmental standards, including laws on take-back and recycling, earlier than other countries. Thus German companies developed expertise in introducing products which require less packaging, are of lower cost and cause less environmental burden.

If environmental regulations are seen as promoting end-of-the-pipe solutions and add-on pollution control systems, the products and processes will get more expensive and less competitive. Such has been the case in the US where regulations in the past have promoted the use of ''Best Available Technology (BAT)'' to reduce pollution. If, on the other hand, regulations permit innovation and flexibility in finding solutions, then the companies can improve on the products and processes to meet the emission and other requirements. As an example, Scandinavian pulp and paper industry developed chlorine-free bleaching process, at the same time carrying out other process improvements. They made significant inroads into the international market and, for some time, were able to charge higher prices for chlorine-free paper.

Just as Deming, Juran, Taguchi and others proved 20 or more years ago that costs can be lowered while improving quality [2], today's companies must think of innovation as a means to reduce environmental burdens, as an additional outcome. In the 'old' days, higher quality was achieved by employing more expensive processes and equipment and by rejecting output which fell below acceptable standards. Thus, if the product and processes were assumed to be 'fixed,' higher quality meant more rejects, hence higher costs. Today we recognize that quality can be designed into a product and that processes can be optimized for higher quality and lower cost.

The inputs (raw material, energy, labor and capital) must be used more efficiently. The processes should eliminate unneeded activities and avoid generating waste products. Use of hazardous materials must be eliminated. While these points seem obvious, companies often do not take advantage of available knowledge. An example is the Green Lights program sponsored by the EPA, which promotes energy savings by improved lighting, with a 2-year payback period. Many companies have not taken advantage of it, because (a) they are not aware of it and, (b) there is resistance to change.

4. A NEW WAY OF LOOKING AT ENVIRONMENTAL REQUIREMENTS

Porter and van der Linde [14] make the point about the new way of looking at environmental aspects in design: ''*Environmental inputs must be embedded in the overall process of improving productivity and competitiveness. The resource productivity model, rather than the pollution control model, must govern decision making.*''

Innovative ways of utilizing the previously wasted by-products yield generous dividends:

- A nylon manufacturer in France invested in recovering a by-product called diacid, which was earlier incinerated. The investment of $12.5 million produced an annual revenue of $3.5 million.
- Dow Chemical plant in California using hydrochloric gas and caustic soda was required to close evaporation ponds containing waste water. By redesigning its process the company reduced both the hydrochloric acid waste and the caustic waste. The company was also able to utilize some of the waste stream as input for other parts of the plant. A cost of $0.25M provided annual savings of $2.4M.
- 3M produces adhesives in batches. Each batch is then added to a storage tank. A bad batch would spoil the whole contents of the tank, with resulting loss of product and time and increased hazardous waste. The company developed new techniques for determining the batch quality faster. The reduction in hazardous waste disposal alone saved it $200,000 annually.
- During the initial start-up of a chemical production, or after an interruption, scrap material is produced. DuPont improved the monitoring equipment, reducing interruptions, waste generation and increasing the plant uptime.
- Regulatory pressures led Ciba-Geigy in its dye producing plant to make changes which not only reduced pollution, but also increased process yields by 40% and annual cost savings of $0.74M.

That laws and regulations can lead to lower product costs and higher productivity has been proven by a number of cases:

- Upon being required to make easier to recycle products, Hitachi redesigned products for easier disassembly, at the same time reducing the parts count (by 16% in a washing machine and by 30% in a vacuum cleaner). The lower parts count also led to lower assembly time and overall, lower costs.
- A 1991 regulation required drastic reduction in benzene emissions during coal tar distillation. It was generally opposed by the industry, since it required costly containment. Aristech Chemical Corporation chose to find solutions to the problem instead. The company found that removing benzene at an earlier processing step did away with the need for containment. Instead of a cost increase, the company saved $3.3M.

Other industries cited by Porter and van der Linde [14], which have used innovation to achieve environmental benefits while at the same time offsetting any associated costs include:

- Paper and pulp industry was required to stop chlorine bleaching, since it released dioxins. It introduced better cleansing processes and substituted O_2, O_3 or H_2O_2 for bleaching and changed to closed-loop processes. By making better use of energy from by-products, it lowered operating costs by 25%. The companies could charge premium prices for chlorine-free paper.

- Paint and coatings industry had to remove volatile organic compounds (VOC) in solvents used. It applied innovations such as low-solvent paints and water-based paints, with better application techniques and use of heat and radiation-cured coatings. The industry was able to charge premium prices for solvent-free paints, offer improved coating quality, have safer working conditions. Materials savings reduced costs.
- Electronics industry also needed to remove volatile organic compounds in cleaning agents. The industry innovated by introducing closed-loop processes, no-clean soldering and non-VOC cleaning agents. Companies achieved improved product quality, reduction in processing cost when cleaning could be eliminated. Pay-back periods of one year were often achieved.
- Refrigerator manufacturers were required to remove CFCs used as refrigerants and reduce energy usage in operation. A propane-butane mix was substituted for the CFCs. Better insulation, gaskets and improved compressors were introduced. The companies showed higher energy efficiency and were able to charge premium prices for ‘‘greener’’ refrigerators. It has been documented that the German branch of the Greenpeace organization was instrumental in promoting this change in the refrigerant.
- Dry-cell manufacturers were faced with having to remove toxic metals such as cadmium, cobalt, lead, lithium, mercury, nickel and zinc in order to reduce toxic wastes going to landfills and into the atmosphere if the cells were incinerated. They innovated by developing nickel-hydride and lithium rechargeable cells. The new products show higher efficiencies and higher energy capacities at competitive costs.

5. END-OF-LIFE STRATEGIES

Stevels and Boks [15] look at the problem of dealing with the product at the disposal stage. The discussion is divided into three main parts: (1) Development of end-of-life systems, (2) plan for end-of-life analysis at the product level, and (3) optimization of the product according to the end-of-life system. The authors propose that the development of such a system involves different end-of-life options, a stepwise plan, followed by a series of actions to complete the process. After choosing a certain end-of-life system the second part describes the development of the system in detail. A key figure shows a flow chart for determining likely end-of-life destinations of product components. In the order of preference, these are: Reuse, high-quality recycling, low-quality recycling, incineration, land fill and chemical waste. Disassembly allows for reuse of part, failing which, mechanical processing can lead to recycling. The rest leads to incineration, landfill, or chemical waste. Under product optimization, the authors provide guidelines for recycling metals, plastics, glass and ceramics, toxic materials and for disposal of waste. Finally, quantitative evaluations of end-of-life systems are shown in the form of LCA, LC costs, and end-of-life costs. Among the data tables included are those showing charges for waste in a treatment plant, grams of material that must be separated to achieve cost-neutral disassembly, compatibilty matrices for diffrerent materials, and environmental impact of recycled materials, versus virgin materials.

Stevels [16] states that in the early years companies took defensive attitudes, e.g., their activities were aimed at "compliance with legislation and toward preventing bad image in the press." However, they also realized cost reductions by measures such as reducing the amount of packaging, using recycled material, reducing energy and material use and reducing the disassembly times. In order for DFE to be most effective, it needs to be integrated into the complete business cycle. It is based on the premise of sustainable development. The company needs to have an environmental vision, leading to an environmental policy, which is embodied in the company's strategies, and finally the company's environmental roadmap. The management of the product creation process under DFE constraints is described in detail. It is suggested that the embedding of eco-design in business take place in three steps, viz., green idea generation, green product creation and the exploitation of the results in the marketplace. A company interested in green marketing should determine the attitudes of its present and potential customers toward green products.

6. CONCLUSION

Product development must look at the whole life cycle of the product. Energy and material use and environmental burden at each life phase of the product must be considered. The following is a partial list of points to be kept in mind

- From the viewpoint of toxic and hazardous substances:
- Do not use hazardous substances in the product.
- The product should not cause hazardous discharges of any kind during use, or after disposal.
- The manufacture of the product should not cause hazardous discharges.
- The materials used in the product should not have caused hazardous discharges during their extraction or preparation for manufacture.
- From the viewpoint of source reduction:

- Measure and account for all the wastes and emissions in the (1) manufacturing process, the (2) distribution, and (3) in product use.
- Redesign the processes and product to eliminate the wastes and emissions.
- Find ways to utilize the wastes.

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