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Towards sustainable product development

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This paper explores some environmental concepts and initiatives which influence the content of the new concept of sustainable product development.

Keywords: environmental concepts; sustainable product development; ecodesign

Introduction

In the area of cleaner production, preventative, proactive and process-integrated approaches have a preference over those that are curative, reactive and end-of-pipe. To maximize the potential of cleaner production it has gradually become accepted that a product orientated approach may be even more attractive than a process orientated one. The main reasons are that it integrates consumer and waste management problems, as well as issues regarding working conditions and current and anticipated problems associated with resource availability. When considering these issues, the product life cycle provides an attractive framework for environmental improvement and innovation. However, a failure with the current product orientated approach has been that too much attention has been devoted to the end-of-life product concerns such as waste problems, take-back, reuse and recycling. What is required is a broader product orientated approach, that considers 'prevention' as a starting point, and moves on to integrated product development that achieves reduced impacts across the whole product life cycle. This approach puts just as much emphasis on whether to make the product at all, and concerns such as resource intensity at the start of the product life, as the end-of-life concerns. Although these are important developments, the environmental optimization of processes and products will not be sufficient to realize the overall objective of sustainable development.

Several environmental concepts exist that either encompass or are related to the relationship between product and environment. They are characterized by the common objective of reducing environmental impacts of products, and some of these concepts are introduced in this paper. The new concept of sustainable product development will then be addressed.

Environmental concepts

In the last ten years, many companies all over the world have become aware of the fact that both economically and ecologically, proactive policies and preventative measures are far more attractive than after-the-event actions and end-of-pipe technologies. As a result, the 'pollution prevention' concept, also known as the 'waste reduction' concept, became increasingly popular. Pollution prevention is defined by the United States Office of Technology Assessment (OTA) as: 'In plant practices that reduce, avoid or eliminate the generation of hazardous waste so as to reduce risks to health and environment'. OTA distinguishes five broad approaches to waste reduction: in-process recycling, process technology and equipment, plant operations, process inputs, and end products.

With respect to end products OTA indicates that changes in the design, composition, or specifications of end-products that allow fundamental changes in the manufacturing process or in the use of raw materials, can lead directly to waste reduction[1].

Part of the pollution prevention concept is that of 'toxics use reduction', which focuses on industrial activities. It encourages greater efficiency, less use of materials, and the reduction or the elimination of toxic substances within production processes. Toxics use reduction specifically addresses the manufacture of products[2,3].

In Canada, a related concept is that of the 'sunset chemicals', which is presented as a coherent and systematic process for the banning or the phasing out of the most harmful chemicals, based on criteria agreed to by government, industry and the public. The 'sunset chemical' process also provides criteria for determining which new chemicals should be licensed. 'Sunset' criteria thus can also be viewed as 'sunrise' criteria[4].

Whereas the pollution and waste reduction activities in the United States have an emphasis on hazardous waste and emissions, the concept of 'waste prevention', which is more common in Europe, has a broader focus. Prevention of waste generation is defined as: 'Activities in production, which consist of the substitution and the reduction of the use of raw materials, the change of the performance of existing and the design of new products and processes resulting in the non-generation or the reduction of waste and/or its pollution potential, in the materials' life cycle'[5].

A concept in the United States which most closely resembles that of waste prevention is the concept of 'source reduction', the objective of which is mainly to reduce the amount of municipal solid waste. In a final report of a Steering Committee on Strategies for Source Reduction, the following national definition is presented: 'Municipal solid waste source reduction is the design, manufacture, purchase, or use of materials or products (including packages) to reduce their amount of toxicity before they enter the municipal solid waste stream. Because it is intended to reduce pollution and conserve resources, source reduction should not increase the net amount or toxicity of wastes generated throughout the life of the product[6].

However, in a more limited and specific definition, source reduction is also used to refer to practices that reduce the use or generation of hazardous substances prior to recycling, treatment, or control[7]. Another concept which is concerned with the character of the industrial chemistry is called 'sanfte chemie' (soft chemistry). It deals with the sustainable use of substances. Ideas are presented on the total metabolism on Earth and how this could be made compatible with nature. It involves the use of renewable resources as raw materials for industrial chemical processes. Biological processes are promoted because of their low temperature and low pressure character and the degradable wastes associated with them. Nature is considered to have a lead in experience regarding the development of substances and products, from which much can be learned in the process of making economic activities compatible with natural cycles. 'Sanfte chemie' has also been presented as the 'detoxification' of industrial chemistry. The increasing usage of enzymes for chemical transformations has also been presented as an aspect of 'sanfte chemie'[8–12].

Part of this approach seems comparable to EPA's 'Design for the Environment'. In the United States the concept of design for the environment (DFE) is defined in various ways. The US Environmental Protection Agency (EPA) has a Design for the Environment Program which promotes the incorporation of environmental considerations, and especially risk reduction, in the design and redesign of products and services. In an EPA leaflet, however, DFE is said to encompass efforts to design products and processes in ways that eliminate or minimize the creation of associated pollution. It focuses on areas which are most familiar to the Office of Pollution Prevention and Toxics of EPA. This means that EPA's DFE concept is strongly determined by their pollution prevention concept. Other important characteristics of the DFE programme are human health and environmental risk issues[13].

In the United States this development is also referred to as 'green chemistry', which is opening a whole new realm of issues in environmental chemistry. Chemists are redesigning commercially important chemical processes and products or inventing new ones to prevent environmental harm in the first place. They are rethinking some of the central processes of industrial chemistry in the name of environmental soundness[14].

'Ecodesign' or 'Design for the Environment'

The concept of 'ecodesign', 'green design', or 'life cycle design', concerns the design of products, by applying environmental criteria aimed at the prevention of waste and emissions and the minimization of their environmental impact, along the material life cycle of the product[15–17].

According to the United States Office of Technology Assessment, green design involves two general goals: waste prevention and better materials management. Here, waste prevention refers to activities of manufacturers and consumers that avoid the generation of waste. OTA states that: 'Examples include using less material to perform the same function, or designing durable products so that faulty or obsolete components can be readily replaced, thus extending the product's service life. Better materials management refers to activities that allow product components or materials to be recovered and reused in their highest value-added application. Examples include designing products that can be readily disassembled into constituent materials, or using materials that can be recycled together without the need for separation'. Part of ecodesign consists of 'design for recycling'[18–21].

In the ecodesign development, more emphasis has gradually been put on product development instead of on product design. As the environmental impact of all products should be minimized, a better approach would be to realize environmentally conscious product development processes. The objective is to formulate improved or new development processes, and at the same time set good examples of novel products with clear environmental characteristics[22–25].

In the USA some work within the concept of 'design for environment' (an area of interest to the EPA Risk Reduction Engineering Laboratory of the Office of Research and Development in Cincinnati) is similar to the European concept of ecodesign. Several publications have been devoted to this, but with a focus which is quite different from that of the EPA Office of Pollution Prevention & Toxics in Washington (EPA's DFE, see above). In those publications, design for the environment is considered to be a practice by which environmental considerations are integrated into product and process engineering design procedures[26–30].

Dematerialization, 'MIPS'

Dematerialization describes a technological shift away from economies based on enormous and increasing consumption of raw materials. Herman *et al.* state that from an environmental point of view dematerialization should perhaps be defined as the change in the amount of waste generated per unit of industrial product. They found that many quantitative questions remain to be answered, for example, the amount of basic material and the number of major products that are used per capita, over time, and what the lifetimes of various manufactured products are[31].

Schmidt-Bleek defines the environmental impact potential of goods as the weighted cradle-to-grave materials inputs per units of services (MIPS) obtainable from a product. It also includes energy inputs either directly or indirectly[32]. In order to achieve both economic and ecological progress in a sustainable way, as Welfens states, it would be necessary to sharply reduce the material intensity per unit service[33]. Schmidt-Bleek states that for a 50% reduction of the global material flows, future infrastructures, installations, products and services have to dematerialize by a factor of 10 compared with current western standards[34].

Design for efficient longevity, 'remanufacturing'

A concept of growing importance is what will be called here 'design for efficient longevity'. Characteristic of this concept is the objective to develop products which last longer, the life of which can easily be extended, and the use of which can be more efficient and more intense. In this respect, new initiatives have been taken in some European countries.

The purpose of product lifetime extension is to conserve resources, to protect the environment and to reduce the costs of solid waste management. Conn found that physical durability is a key factor affecting the lifetimes of a few of the products he examined, while the lifetimes of other products seem more dependent on the consumer's desire to change[35]. An OECD study identified two primary goals towards which a policy of product life extension may be directed: reduction of post-consumer waste by reducing the volume of the products manufactured; and, in the same way, reduction of the quantity of primary materials used in the manufacture of durable products[36].

Börlin and Stahel studied product life extension as a central issue in the prevention of waste, in six industrial cases. They concluded that interesting opportunities exist. It is significant that long product life can be made compatible with technological innovation by practising modular design. This facilitates the renewal of components instead of the exchange of the entire product. Part of the concept is the demanufacturing or the remanufacturing of products[37,38]. Börlin and Stahel state that their study proves that: 'durability is cost-effectiveness is modernity,'[39]. Some other studies have confirmed this finding[40,41].

Collective use, as part of this area, has also been studied. It can mean shared use, prolonged use (use after each other) and also better and more intensive use. Conclusions of a seminar were, among others, that good design is simple and that system solutions may be one of the design strategies of the future[42].

Ecocycle society

'Sustainable development' is defined by the World Commission on Environment and Development as: 'Development that meets the needs of the present without compromising the ability of future generations to meet their own needs. It contains within it two key concepts:

- the concept of 'needs', in particular the essential needs of the world's poor, to which overriding priority should be given; and...
- the idea of limitations imposed by the state of technology and social organization on the environment's ability to meet present and future needs'[43].

It is against this background that, in some countries (Germany, The Netherlands, Denmark and Sweden), new concepts are being developed and implemented which are concerned with the material throughput of society. In Sweden, for example, the ecocycle society concerns a society with cyclic management of goods and production, with reuse and reclamation. The objective is to realize more efficient use of resources and reduced amounts of waste[44]. In Germany, this objective has already existed for some time. Here the 'Kreislaufwirtschaft' strives for the highest possible use through products that are produced from renewable resources, and the components of which can be reused to a large extent[45].

However, an ecocycle economy, according to Schnitzer, needs energy which is not connected to matter. This means that only solar energy would be appropriate. Electricity, as a form of energy that is simple to transport and can be used effectively, thus plays an important role. He underlines that it is more important to keep the changes in the resource stocks as small as possible, than to reduce or return material flows[46].

In a similar description of the ecocycle economy as a new technological and economic paradigm, Narodoslawsky is of the opinion that non-durable products should be based on renewable resources. They pass through the so called 'biocycle', in which resources are built by photosynthesis from substances in the biosphere. The energy used in the biocycle should only consist of solar energy, implying a shift away from fossil fuel. Materials that originate from non-renewable resources will be fed into the 'mineral cycle'. The main streams of this are technical construction flows and reuse flows. Mineral substances are to be used as long as possible. The basic energy in this case originates mainly from the sun.

Between these two cycles, the biocycle and the mineral cycle, Narodoslawsky suggests, there will be no exchange. The biocycle serves for short-life products and the mineral cycle for durable products[47].

Sustainable product development

One of the most recent developments is the emergence of the concept of 'sustainable product development', which deals with elementary demands, essential product functions, the systems in which products function, the nature, availability and selection of resources, and the distribution of those resources among nations and generations.

Distinct from the concepts of ecodesign and design for the environment, sustainable product design goes beyond environmental optimization of products and services, attempting to incorporate the following considerations.

The western world has for many years been characterized by an enormous throughput of resources and energy. It represents 20% of the world population and uses 80% of the material and energy resources annually extracted and exploited. This means that a tremendous amount of material 'capital' has already been invested in the developed countries. Vast amounts of natural resources have been taken from sources in the developing world.

Much of the environmental impact along the life cycle of a product is located at the early stages, e.g. the extraction, the refining and the processing stages. The countries that have made their resources accessible for extraction and distribution were presented with the devastation of natural conditions and the associated wastes, emissions and pollution.

The industrialized world has to recognize its global environmental impact and should act accordingly. It will have to reconsider and redesign its materials policies. This should lead to better usage of the materials that have already been imported and that are present and available in all kinds of material structures, objects and products.

Any further and future exploitation and import of natural resources should be based on existing and improved knowledge of the environmental properties of those resources. The present material stock of industrialized countries can be considered as the remaining visual representation of the environmental damage that has already been caused in the previous (often remote) material life cycle stages.

The environmental properties of resources should be of decisive importance in the determination of a resource use policy, which takes account of the specific product requirements as well as the environmental product life cycle implications.

It may be essential to initiate preparatory materials policies and sustainable product development processes on the basis of an analysis of a virtual scarcity of resources on the one hand, and a multitude of conflicting demands on the other hand.

Increasingly, the moral obligation is emerging which takes responsibility for an equal distribution of the remaining natural resources over nations and generations. Clearly, with less resources and more knowledge about their environmental properties becoming available, the need to establish international as well as national resources policies is getting stronger. Central considerations in these policies will be, on the one hand, present and future availability and, on the other hand, elementary needs and the number of people that could benefit from the resources.

In combination with resource use selectivity, it is important to utilize resources, substances, materials, product components, products and product systems to their fullest potential[48].

Sirkin presented cascading as a tool for resource conservation. He views cascading as a way for repeatedly utilizing the quality of a resource on its path to equilibrium[49]. The concept is developed and more comprehensively dealt with in the theory of resource cascading of Sirkin and ten Houten, which builds upon four principles. The first is 'appropriate fit', which means that the quality of a resource should be in harmony with the scope and difficulty of the required task. The second is 'augmentation', which relates resource quality to utilization time. The third is 'consecutive relinking' which deals with the salvaging and recirculation of substances. The fourth principle is that of 'balancing resource metabolism', which calls for a balance between the volume and flow rate of resources entering into and circulating within the system and the amount of resource regeneration effected by the system[50].

In lowering, especially in industrialized countries, the level of overall material use, and hence reducing the adverse effects of wastes and pollutants, the quality of the environment would benefit tremendously. This would also save our resources. For that purpose, directions should be established concerning the type of materials to be used and their future destination in processes and products. Also, a diversity of chemical substances shoud be used which is compatible with nature and not exotic or in opposition to it. Sound raw materials policies would favour renewable resources over non-renewable, abundant resources over those that are scarce, and less polluting over clearly polluting resources.

This could mean that issues such as the nature and volume of production and consumption will receive increasing attention. In product development more emphasis will be put on questions regarding actual needs and wants, required functions and new creative and environment orientated ways of meeting acknowledged and respected demands. Subject such as elementary needs, life cycle design, product systems, product durability, long-term resource availability and natural compatibility, will be central to the concept of sustainable product development[51–53].

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