Manufacturing and the Environment

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The Industrial Revolution transformed society and its interaction with the environment, increasing the use of natural resources and the pace of development of new products and processes. This has left permanent changes in the structure of society and also on the earth through depletion of resources, alteration of natural habitats and pollution from unwanted by-products of the production process and discarded products at the end of their useful life. Recently, concern for the environment has led manufacturing industry to take a proactive role in the development of cleaner manufacturing processes and the design of recyclable products. The goal is sustainable development, where the waste from one process becomes the raw material for another in a large cycle which imitates the natural food chain.

This paper outlines the requirements for such sustainable development, and gives an example of the elimination of unwanted by-product through the use of dry cutting.

Keywords: Clean manufacturing; Design for environment; Dry cutting; Environment; Industrial ecology; Sustainable development

1. Introduction

Because of the many accidents and disasters which have occurred since the Industrial Revolution, public and media attention has become much more focused on environmental issues. Figure 1 depicts the relationships that exist between government, industry and the public. The role of government is to legislate for the public good, and though it will foster economic growth, it must also ensure that workers, the general public and the natural environment are adequately protected. Pressure has been mounting on all industry sectors to improve their environmental performance substantially. The industries that came under scrutiny initially were those in the chemical process and heavy industry sectors; however, environmental issues are now a matter of concern for organisations of all sizes in all sectors. The outlook and response of industry to mounting environmental pressures is summarised in Fig. 2. This response is typical of the more progressive organisations; significant time lags are present in the response of individual companies and between industries in different countries. As industries progress from Stage I to Stage III, traditional prac-

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tices must be set aside and a new paradigm adopted [1,2]. This has been termed “Paradigm E” and is illustrated in Fig. 3.

In the quality revolution, defects were viewed as symptoms of inefficient product or process design. Pollution and waste similarly can be viewed as a sign that resources have been used incompletely, inefficiently or ineffectively [3]. It is now accepted that innovation can improve product quality while lowering costs. In the same way, there are considerable opportunities to reduce pollution and waste, through innovations in product design and production processes, which will also lead to substantial cost savings and improved competitiveness.

2. Industrial Ecology

The basic principle of industrial ecology was recognised some 500 years ago by Leonardo da Vinci when he penned these words:

"Although human genius through various inventions, makes instruments corresponding the same ends, it will never discover an invention more beautiful, nor more ready, nor more economical than does nature, because in her inventions nothing is lacking and nothing is superfluous" [4].

Industrial ecology seeks to optimise the total industrial cycle from virgin material to finished material to component to product and to ultimate disposal. Factors to optimise include resources, energy and capital [5]. Biological ecosystems show a high inter-dependence of organisms, the waste from one forming the energy source for another in a continuous cycle. While the analogy is not complete, an industrial ecosystem is one in which each process and network of processes must be viewed as a dependent and interrelated part of the larger whole. Ecosystems have been classified into three main categories.

**Type I System**

The Type I system (Fig. 4) is the most primitive class where the flow of resources is linear, and the ecosystem component has no concern for resources and waste. Many paper products, plastics and metals are embodied in products which flow directly to consumers, are used and then are discarded to sinks and landfills. In many cases materials are removed from a state of relative order (e.g. ore or fossil fuel), made more orderly through energy intensive processes (e.g. smelting or refining) and then placed in a state of extreme disorder from whence recovery is unlikely given the highly disordered state of the waste material [5].

**Type II System**

Industrial systems are currently under pressure to evolve from a linear (Type I) to a semicyclical (Type II, Fig 5) mode of operation. Industrial processes can be conveniently considered in terms of four major components: the materials extractor (primary processor), the manufacturer (secondary processor), the user and the waste processor. To the extent that they perform operations in a cyclic manner or organise cyclic flow within the entire industrial ecosystem they evolve into modes of operation that are less disruptive to external support systems. Waste in an industrial context should be regarded as residues that we have not learned to use efficiently. As our understanding of processes and materials increases, then the amounts of waste material and waste energy produced should diminish.

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**Fig. 4. Type I system, linear.**

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**Fig. 3. Evolution of manufacturing paradigms [2].**