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"Summary of article by T.E. Graedel, B.R. Allenby and P.B. Linhart: Implementing Industrial Ecology"

Industrial Ecology (IE) can be defined as a concept wherein "economic systems are viewed not in isolation from their surrounding systems, but in concert with them. As applied to industrial operations, it requires a systems view in which one seeks to optimize the total materials cycle from virgin material, to finished material, to component, to product, to waste product, and to ultimate disposal. Factors to be optimized include resources, energy, and capital."(18) This paper discusses some issues related to the industrial ecology of manufacturing processes.

SYSTEMS DESCRIPTION

R.A. Frosch and N. Gallopoulos[1] have argued that industrial systems should attempt to mimic the biological ecosystem. Biological ecosystems are a complex network of processes in which everything produced is used by some organism for its own metabolism; the wastes of one organism are food for another. During the earliest periods of life on earth, material cycles were actually linear systems in which organisms had unlimited resources and produced wastes without recycling. As resources became limited, flows into and out of the ecosystem (resources and wastes) became limited while recycling increased, i.e., the flow of materials became semicyclic. While this type of materials flow is more efficient than the linear system, it is still not sustainable over long periods of time. To achieve sustainability, ecosystems have evolved to become almost completely cyclical; resources and wastes are undefined, as residues from one component of the system are resources for another. The only exception to complete cyclicity in the biological ecosystem is that energy in the form of solar radiation enters as an outside resource.

During a period of global plenty, the industrial revolution, coupled with increases in the human population and agricultural production, lead initially to the development of industrial processes similar to the linear systems described above. However, the effects of both resource constraints and limited waste disposal sites are beginning to set in. There is increasing pressure to change the patterns of material flows in industrial systems from linear to semicyclic. Industrial ecology is intended to promote this transformation in an efficient manner. The domain of IE consists of four central nodes: the materials extractor or grower, the materials processor or manufacture, the consumer, and the waste processor. Processes should be set up to ensure that there are cyclical flows between these four nodes, thus reducing their disruptive impact on external support systems.

RESOURCE FLOWS

Applied industrial ecology studies the factors that influence the flows of selected materials between economic processes. The overall industrial ecology cycle can be divided into three stages:

1) **Industrial Production of Materials:** This stage begins with virgin materials and proceeds through the processes of extraction, separation or refining, and physical and chemical preparation to produce the finished material. Both recycling and disposal of waste materials occur between some of these stages.

2) **Industrial Manufacture of Products**: A number of finished materials will enter this stage of the manufacturing process, and then go through the forming, finished components, and fabrication stages to create finished products. Industrial physical designers are concerned with the material flows within this process, i.e., waste flows, recycled material flows, and in-process recycle flows. Optimizing the industrial ecology implies increasing the recycle flows and reducing waste disposal. This optimization may involve trade-offs between the purity of the finished product on the one hand, and reduction in the use of materials on the other.

3) **Customer Product Cycle:** Customer decisions are made independently of the production of materials and the manufacture of products. Finished products are used by consumers, and they may then either be recycled or disposed of when they become obsolete. Industrial ecology moves toward optimization as recycling is favored over disposal.

APPROACHES TO INDUSTRIAL ECOLOGY

Industrial ecology analysis can be material specific or product-specific. Human institutions can promote or constrain desirable material flows, and both social pressures and private profit may be needed to develop a sound industrial ecology. Price incentives can be used in some cases to correct for externalities that may work against sound industrial ecology practices. In other cases, the desired results must be achieved by regulations such as the Clean Air Act.

In developing industrial ecology models, the industrial system should be viewed as part of a larger system. The problems must ultimately be posed in the framework of mathematical models. Input-output models and linear and nonlinear programming are all mathematical tools that can be used to model the industrial ecology cycle. The challenge, however, lies not in solving the mathematical model, but in using appropriate insight and information in defining the magnitudes of the interactions among the components of the industrial ecology cycle.

Notes

1. R.A. Frosch and N. Gallopoulos, "Towards an Industrial Ecology," paper presented to the Royal Society, London, February 21, 1990.