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Industrial Ecology : Concepts, System View and Approaches

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ABSTRACT Industrial ecology is a new approach to the designing and operating industrial systems as living systems interdependent with natural systems. It is a concept in which an industrial system is viewed not in isolation from its surrounding systems but in concert with them. It seeks to balance environmental and economic performance within emerging understanding of local and global ecological constraints. Some of its developers have called it "the science of sustainability". Industrial ecology seeks to optimize the total materials cycle from raw material to finished material, to component, to product, to waste product, and to ultimate disposal. We can say that Industrial Ecology is:

- The study of the flows of materials and energy in industrial and consumer activities.
- The study of the effects of these flows on the environment.
- The study of the influences of economic, political, regulatory, and social factors on the flow, use, and transformation of resources.

Industrial Ecology: A Systems View

Traditional biological ecology is defined as the scientific study of the interactions that determine the distribution and abundance of organisms. The relationship between this concept and that of industrial activities has been discussed by Frosch and Gallopoulost.

In a biological ecosystem, some of the organisms use sunlight, water, and minerals to grow, while others consume the first, alive or dead, along with minerals and gases, and produce wastes of their own. These wastes are in turn food for other organisms, some of which may convert the wastes into the minerals used by the primary producers, and some of which consume each other in a complex network of processes in which everything produced is used by some organism for its own metabolism. Similarly, in the industrial ecosystem, each process and network of processes must be viewed as a dependent and interrelated part of a larger whole. Industrial Ecology lays stress on a systemic approach. This means that instead of considering individual elements of a system in isolation, the entire system is viewed as a whole. For example, if we were to consider the environmental impact of an automobile, instead of just considering the pollution from an automobile plant, we study the entire automobile system involving, the production of the automobile, emissions from them, the impact of the road system (construction, maintenance etc.), the recycling of components and, their ultimate disposal. And of course, the kind of fuel the automobile uses (as this is by far the main impact of the automobile in its present form).

To make this simple, we can take another example. Here we take the most common problem from day to day life; pollution from vehicles on the roads. If we were to take a systems view, we

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would need to consider many other solutions to alleviate vehicular pollution other than the obvious one such as installing catalytic converters. We would need to understand why people travel and consider solutions to minimize this need to travel – by planning towns better, bringing services closer to people so that people do not have to travel, by improving public transport to reduce the number of vehicles on the road etc. Of course, any such systemic solutions cannot be immediate and for the short term, some conventional solutions are essential. However, the systemic solution is more lasting and creates a clear road map for the future.

It is left to the user to define "the system" for study. The system can be a geographical area such as a city or a region. Else, one can define the "system" as the jute industry in Bangladesh. The definition of the "system" depends on the purpose for which the research is being done as well as the researcher's perspective.

"Industrial Ecology" explores the idea that industrial activities should not be considered in isolation from the natural world but rather as a part of the natural system. In fact industrial systems should be viewed as *industrial ecosystems* that function within the natural ecological system or biosphere. The industrial system, in a similar way to the natural ecosystem, essentially consists of flows of materials, energy and information, and furthermore relies on resources and services provided by the biosphere. It is important to stress that the word 'industrial', in the context of "Industrial Ecology", refers to all human activities occurring within the modern technological society. Therefore, tourism, housing, medical services, transportation and agriculture are all part of the industrial system. And the word 'ecology', here, refers to the science of ecosystems.

Industrial ecology is a branch of systems science and systems thinking. These terms are over-used and often abused. Here is a brief introduction to what we mean when we use them, and how they relate specifically to industrial ecology.

- A system is a set of elements inter-relating in a structured way.
- The elements are perceived as a whole with a purpose.
- The elements interact within defined boundaries.
- A system's behavior cannot be predicted by analysis of its individual elements.
- The properties of a system emerge from the interaction of its elements and are distinct from their properties as separate pieces.
- The behavior of the system results from the interaction of the elements and between the system and its environment. (System + Environment of System = A Larger System)
- The definition of the elements and the setting of system boundaries are subjective actions. So the assumptions of the definers or observers of any system must be made explicit.

Systems science ranges from highly theoretical work defining research methods to applied work in virtually all areas of life (often called "systems practice"). Some modes of applying systems thinking include the learning organization, systems dynamics, sociotechnical systems, and the viable system model. In this time of complex and rapid change, systems thinking has immediate, pragmatic value for companies and agencies of any size.

Applying Industrial Ecology:

The Kalundborg Example

A process of "Industrial Symbiosis", which has evolved during the last three decades in the small city of Kalundborg, in Denmark, offers the best evidence that such an approach can be very practical and economically viable. IT is a successful example of an industrial complex minimizing pollution and optimizing the use of various resources.

A few industries located there, including a power plant, a gypboard plant, a biotech unit, the fishing activity in the town and the town municipality developed a method of sharing each other's wastes to mutual advantage. The material flows between industries in Kalundborg for the year 1999 are shown in the figure below. Ever since the initial discovery of these interactions in 1989, the economic and environmental benefits along with specific details of resources being shared by industries in Kalundborg.

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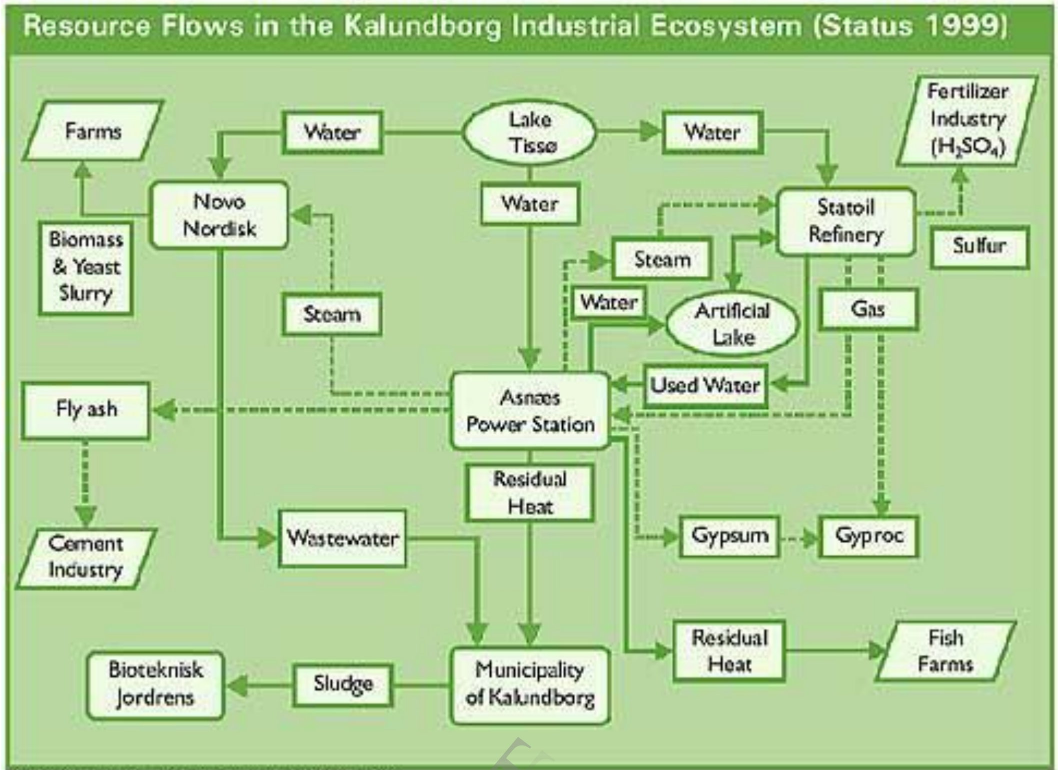

Source: C. Francis, adapted from Christensen, 1999.

Constraints and Incentives for Industrial Ecology:

Industrial ecology cannot be studied and optimized in isolation from the human institutions of various kinds that promote or constrain the materials or energy flows :

(i)Engineering excellence can often promote cyclic behavior within the manufacturing node by designing processes to promote materials reuse.

(ii) The desire to avoid toxic wastes may promote process changes to reduce the quantity of wastes or (better) to substitute materials or components that result in less toxic or nontoxic wastes.

(iii) The economic system may make it difficult to raise capital to alter a process and render it more efficient, that is, to improve its cyclic nature.

(iv) Taxation may promote raw materials flows or import export flows that are contrary to cyclization of the industrial ecosystem.

(v) Government regulations may make reuse of materials so difficult that enhanced waste flow is defact encouraged.

(vi) The price system, by failing to include relevant externalities in prices and costs, may preclude adoption of industrial ecology by manufacturers and producers.

(vii) The standard of living of the consumer may encourage long product use or, alternatively, may promote early product disposal.

(viii) The rapid rate of technological evolution and obsolescence contributes to an enhanced waste stream.

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Summary

The principal objective of Industrial Ecology is to reorganize the industrial system (including all aspects of human activity) so that it evolves towards a mode of operation that is compatible with the biosphere and is sustainable over the long-term. Industrial Ecology, also known as the science of sustainability, is the discipline that measures and recommends ways to manage resources in a sustainable manner. The strategy for implementing the concepts of Industrial Ecology is often referred to as eco-restructuring and can be described in terms of four main elements:

- Optimizing the use of resources
- Closing material loops and minimizing emissions
- Dematerializing activities
- Reducing and eliminating the dependence on non-renewable sources of energy

The potential advantages to be gained through industrial ecology and the great disadvantages to all of us if the tenets of industrial ecology are not followed.

A simple and useful synopsis is to determine several characteristics of industrial ecology that, in one way or another, permeate the papers that follow:

(i) Industrial ecology is proactive not reactive. That is, it is initiated and promoted by industrial concerns because it is in their own interest and in the interest of those surrounding systems with which they interact, not because it is imposed by one or more external factors.

(ii) Industrial ecology is designed-in not added-on. This characteristic recognizes that many aspects of materials flows are defined by decisions taken very early in the design process and that optimization of industrial ecology requires every product and process designer and every manufacturing engineer to view industrial ecology with the same intensity that is brought to bear on product quality or manufacturability.

(iii) Industrial ecology is flexible not rigid. Many aspects of the process may need to change as new manufacturing processes become possible, new limitations arise from scientific and ecological studies, new opportunities arise as markets evolve, and so on.

(iv) Industrial ecology is encompassing not insular. In the modern international industrial world, it calls for approaches that not only cross industrial sectors but cross national and cultural boundaries as well.

"Restructuring a system doesn't mean shoving people or things around, bulldozing, rebuilding, hiring, firing -- that's not what changes system behavior. Almost always, the most effective restructuring means putting information into a place where it doesn't now reach, or changing goals, rewards, incentives and disincentives, so that the same people, in the same positions, make decisions in a different way. Restructuring a system means changing what's in people's heads."

-- Donella Meadows, co-author, Beyond the Limits to Growth

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