INDUSTRIAL ECOLOGY, WATER RESOURCES, AND DESALINATION

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Summary

Sustainable development refers to the fulfillment of human needs through simultaneous socioeconomic and technological progress and conservation of the earth's natural systems. Sustainable world progress is dependent upon continued economic, social, cultural, and technological progress. Industrial ecology provides a conceptual framework for understanding the impacts of industrial systems on ecosystems and the natural environment. More importantly, it attempts to identify trustworthy production processes that minimize harm to the natural environment and ecosystems, satisfy human needs, and provide competitive advantages to the enterprises that implement these processes. The ultimate objective is sustainable development. Industrial ecology involves the study of interactions, among elements of a system and is inherently associated with identifying and implementing strategies for industrial systems to emulate more closely sustainable, ecological systems. An objective of industrial ecology is to change the nature of earlier industrial life cycles – where raw materials are used and products, by-products, and wastes are produced – to a cyclic system where wastes are reused as energy or raw materials for another product. Industrial ecology is, in part, concerned with the identification of flows of energy and materials through various systems, a concept sometimes referred to as industrial metabolism. Through this, it is hoped to minimize the ecological burdens and the resource efficiency of natural resource use within industrial systems. This paper discusses management strategies for

sustainability and the development of appropriate life cycles for industrial processes that assist in the attainment of sustainable development which take into consideration risks, uncertainties, and information and knowledge imperfections. We specialize some of these discussions to the important area of water resource systems engineering and desalination as technologies in support of enhanced sustainability. These issues are particularly important at this time since water is a vital resource which is necessary for all aspects of human and ecosystem survival and health and potable water is inadequate in many parts of the world. New apprehensions have been raised about growing water scarcity and contamination and the likely inability of meeting the water requirements of a rapidly growing world population. Thus, the use of industrial ecology and systems engineering and management approaches to enhance water resource availability is a timely subject and the one explored here.

1. Introduction

Industrial ecology is a concept in systems analysis and engineering that allows us to structure and understand interactions between industrial systems and other systems, in particular natural systems. Although there have been many early efforts to understand systems and their interactions, the early efforts of Forrester (1969, 1971) at MIT in looking at the world as a set of interacting dynamic subsystems are particularly notable. These early studies examined the city and the world as coupled non-linear dynamic systems. Meadows et al. (1981, 1992) extended this work in their work on *Limits to Growth*, which was initially published in 1972. By using systems dynamics modeling approaches that are now relatively common in systems engineering efforts (Sage and Armstrong 2000), trends in various policy settings were modeled. Of particular note here are the world dynamics modeling efforts in which environmental degradation trends in the world were modeled based on very simple assumptions, highlighting unsustainable courses of action in these simplified models.

Ayres (1989, Ayres and Ayres, 1996) developed the notion of industrial metabolism, defined to be the use of materials and energy by industry and the way these materials flow through industrial systems, are transformed, and then dissipate as wastes. In another early article, Frosch and Gallopoulos (1989), in their important article “Strategies for Manufacturing”, discussed industrial ecosystems concepts and this led to one of the first uses of the term “industrial ecology”. In this work, an ideal industrial ecosystem functions in a related manner to a biological analog. This allegory between industrial and natural ecosystems is the basis of industrial ecology and was used to suggest that wastes produced by one product would be used as resources by another such that, ideally, wastes would not leave the total industrial system to impact negatively on natural systems. In 1991, the National Academy of Science held a symposium on industrial ecology and, in 1994, published *The Greening of Industrial Ecosystems* (Allenby and Richards 1994) which collected many earlier efforts of using systems approaches to resolve complex industrial issues with environmental and ecological interactions as well as interactions with economics, law, and public policy. This book identifies a number of tools for industrial ecology, such as design for the environment, life cycle assessment, life cycle design, and environmental accounting. It also discusses the interactions between industrial ecology and other disciplines such as law, economics, and public policy.

There are a number of strategies used to reduce the ecological and environmental impacts of industrial activities. Some of these are described here.

(a) Clean production, sometimes called pollution prevention, involves the use of materials, processes, or practices to reduce or eliminate the creation of pollutants at the source. It is generally a term used to refer to specific actions by individual firms, rather than the group activities of an industrial system.
(b) Design for environment (DfE) (sometimes called life cycle design (LCD)), efforts are concerned with creating eco-efficient products and processes that fulfill human needs, individually and societally. LCD is a systems engineering-oriented approach for designing more ecologically and economically sustainable products and services through the integration of environmental requirements into each life cycle phase such that the total harmful impacts of a product are reduced. DfE (Fiskel 1998) is a essentially equivalent concept although its intellectual roots are somewhat different, DfE having come as an outgrowth of various "design for X" methods, where X can represent manufacturability, testability, reliability, or other "ilities" and design considerations.
(c) Life cycle assessment (LCA) is a systems engineering method for evaluating the environmental effects of a product or production process through its entire life, from initial creation to ultimate disposal. This generally involves a three-phase effort that results in the definition, development, and deployment of options. These are commonly denoted in the LCA literature as (i) inventory formulation, which results in the definition of requirements for the effort, associated identification of natural resource use and environmental discharge, and potential action alternatives, (ii) impact analysis, which represents the characterization and assessment of consequences of life cycle efforts on the environment of various change alternatives, and (iii) interpretation and improvement, which involves implementation of the best alternative opportunities to reduce environmental burden and enhance process and product value. LCA provides a potentially capable tool of identifying and implementing strategies that reduce the environmental and ecological impacts of products and processes as well as evaluating cost and effectiveness merits of various product and process options. Much current effort is under way to develop LCA approaches at this time (Graedel 1998).
(d) Source reduction is the effort of reducing the amount of hazardous substances, pollutants, or contaminants that that would otherwise enter a waste stream or be released into the environment prior to the waste being recycled, treated, or otherwise disposed of. Waste minimization involves the reduction of hazardous waste that is generated through subsequent treatment or disposal.
(e) Total quality environmental management (TQEM) is an effort to monitor, control, and improve environmental performance within individual organizations. It is related to total quality management principles and integrates environmental considerations into all aspects of the systems management, processes, and products of an organization.

Industrial ecology concepts were in very early stages of development in the mid–1970s, although the term itself was not used. To a considerable extent, the considerable intellectual activity associated with the United Nations Environment Program (UNEP) was a catalyst for industrial ecology-like efforts. The United Nations Industrial

Development Organization (UNIDO) and the United Nations Economic Commission for Europe (ECE) also played a role in encouraging interests in this subject. Papers, for example, presented during an ECE international seminar in 1976 on "Non-waste Technology and Production" contained some ideas comparable to those discussed in the cleaner production, LCA, and industrial ecology literature. *Agenda 21* also contains much content of relevance to industrial ecology, although the explicit use of the term does not seem to appear there. We now turn our attention to some of the motivations provided by *Agenda 21* for industrial ecology.

2. *Agenda 21* and the Need for Systems Engineering and Industrial Ecology

Agenda 21 is a massive document. Major parts of it are discussed in this encyclopedia in the article on sustainable development, water resources, and industrial ecology. There are a number of relationships between *Agenda 21* and the need for systems engineering and industrial ecology for sustainability. In this section, we examine some of these in terms of the *Agenda 21* report chapters that relate most directly to these needs and associated efforts at the provision of desalination plants and services.

2.1. Chapter 30. Strengthening the Role of Business and Industry

In this chapter, it was noted that business and industry have crucial roles in ensuring sustainable development. This is so as private sector technoeconomic initiatives, within a free market framework, represent the leading provider of material goods and services that enhances opportunities for advancement in the social and cultural well-being of humans. Environmental and ecological harm have often been due to past industrial developmental activities. This suggests the need for appropriate knowledge of the many areas that impact on sustainable development, as well as concern with legal and regulatory frameworks, enlightened systems management in the private sector, and appropriate public sector institutional frameworks and infrastructures. Without all of these, increased industrialization can create the ecological and environmental impacts that jeopardize the very well-being that are the objectives of industrialization.

Accomplishing this should be a very important objective for enlightened business and technology leaders and for governments and non-governmental organizations. It is vital to identify paths of technoeconomic development that enhance the capabilities of industry to improve opportunities within and across nations. Two major program areas and objectives are described in Chapter 30.

(a) Clean production is encouraged through the development of engineering and management practices that minimize waste throughout the product life cycle and which ensure optimal efficiency at each phase of the product life cycle and competitiveness of industrial units. Efforts to increase the efficiency of resource utilization, through such efforts as increased reuse and recycling of residues and overall reduction in the quantity of waste discharge per unit of economic output, are suggested. Other suggested mechanisms include industrial partnerships and technological cooperation, internalization of environmental costs into accounting and pricing mechanisms, legislation and standards as well as voluntary initiatives in adopting codes of conduct and increased education and information dissemination

concerning clean production methods.
(b) Promoting responsible entrepreneurial efforts was noted as a powerful force for innovation, efficiency, and effectiveness. Venture capital funding mechanisms and easy transfer of environmentally and ecologically sound technologies to developing nations was encouraged.

Chapter 30 of *Agenda 21* has a particular focus on business and industry. Other chapters of *Agenda 21* deal with institutional arrangements, regulatory and enforcement roles of governments, and other mechanisms and instruments that may influence the operations of business enterprises for enhanced sustainable development.

2.2. Chapter 31. The Scientific and Technological Community

The major issue addressed in this chapter was enabling the scientific and technological community, defined as "… including among others engineers, architects, industrial designers, urban planners, other professionals and policy makers …", to make more open and effective contributions to decision-making processes relating to environment and sustainable development. Also encouraged were more cooperative two-way relationships with this community and the public, decision makers, and government officials.

Two program areas and associated objectives were stressed in this chapter.

(a) Improved communication and cooperation between the scientific and technological community and government decision makers and the public.
(b) Establishment of codes of practice and guidelines related to science and technology, such as to enhance the integrity of life-support systems and increase ethical awareness and professional responsibility by scientists and technologists.

2.3. Chapter 34. Transfer of Environmentally Sound Technology, Cooperation and Capacity-Building

This chapter related to the need for education and training in development and use of environmentally sound technologies. It was recognized that the availability of scientific and technological information and access to and transfer of environmentally sound technology were essential requirements for sustainable development. The activities suggested here were intended to improve conditions for information dissemination, access to and transfer of appropriate technologies, and capacity building and cooperation in technological efforts.

Five major objectives were identified:

(a) To improve access to scientific and technological information.
(b) To promote, facilitate, and finance access to and transfer of technologies.
(c) To facilitate maintenance and promotion of indigenous technologies.
(d) To strengthen the capacity of nations to assess, adopt, manage, and apply technologies through such activities as human resource development, the development of institutional capacities, and integration of technology assessments

and transfers with national needs, objectives, and priorities.
(e) To promote long-term partnerships between developers and users of technologies.

Of course, these objectives need to be accomplished with an awareness of how technology is developed and dispersed or transferred. There needs to be realization of the fact that a technology is not simply information and knowledge, it is also a fundamental business commodity. Thus, concern needs to be associated with knowledge management and transfer of intellectual property and patent protection to protect this commodity. Supportive institutions and infrastructures are a major need in this as well. Of course, there are major linkages and interactions with these efforts and issues that affect such concerns as education, poverty, income distribution, and gender matters. The chapter places appropriate emphasis on capacity building as a necessary complement to technology transfer. Identification of the most relevant technologies for transfer and the associated institutions and infrastructure arrangements to make these efforts ultimately fruitful is very important also. There is also major interaction with these efforts and the efforts discussed in Chapters 37 (National Mechanisms and International Cooperation for Capacity Building) and 33 (Financial Assistance).

2.4. Chapter 40. Information for Decision-Making

Information and associated knowledge is an important and powerful resource in support of sustainable development and this is the subject of much of *Agenda 21*. It is particularly emphasized in Chapter 40. where it is stressed that appropriate decisions must be based on trustworthy information. It is suggested that emerging global information resources and new information and communications technologies are very important for success and that this will require availability and accessibility of information in developed and developing nations alike. It indicates that inadequate management of information, often resulting from a lack of financial resources and appropriately educated workers, is a reality in many nations. It addresses the need for mechanisms which can address and ameliorate these difficulties.

Two program areas and associated objectives are identified in Chapter 40.

(a) Bridging the data gap in order to accomplish cost-effective and relevant data collection and to strengthen the capacity to analyze data and convert it in a timely manner into information and to make this information accessible is a major need.
(b) Improving the availability of information in order to strengthen existing mechanisms of information processing and to strengthen information handling and communication capabilities such as to ensure full participation of nations is also a major need.

This chapter infers the need for national information and communications policies that address the infrastructure requirements for information and knowledge and the associated needs in the public and private sector for trustworthy information.

Standards that enhance sustainability are suggested in *Agenda 21*. Two major international standards are, in large measure, directed at these ends as well and we now discuss these.

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