THE INDUSTRIAL SYSTEMS' ENVIRONMENTAL IMPACTS ON ECOLOGICAL SYSTEMS

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Abstract: *Industrial Ecology is an emerging field that focuses on the twin goals of economic development and environmental quality. The concept requires that an industrial system be viewed not in isolation from its surrounding systems, but in concert with them. It is a systems view in which one seeks to optimize the total materials cycle from virgin material, to finished material, to component, to product, to obsolete product, and to ultimate disposal. Factors to be optimized include resources, energy, and capital. Human beings are only one component in a complex web of ecological interactions: their activities cannot be separated from the functioning of the entire system.*
Key words: *industrial ecology, environmental quality, ecological systems*

1. INTRODUCTION

Industrial ecology is the study of the physical, chemical, and biological interactions and interrelationships both within and between industrial and ecological systems. Additionally, some researchers feel that industrial ecology involves identifying and implementing strategies for industrial systems to more closely emulate harmonious, sustainable, ecological ecosystems [1].

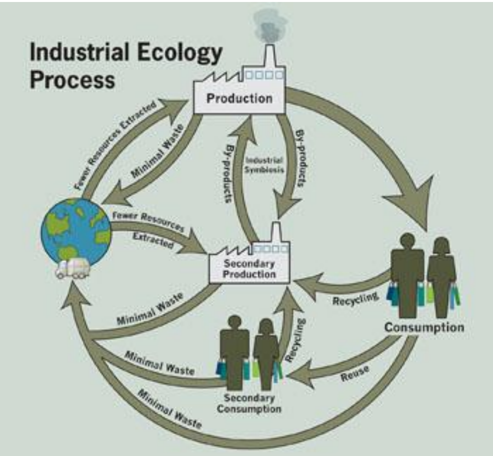

Fig. 1 Industrial ecology process

Fundamental to industrial ecology is identifying and tracing flows of energy and materials through various systems (Figure 1). This concept, sometimes referred to as *industrial metabolism*, can be utilized to follow material and energy flows, transformations, and dissipation in the industrial system as well as into natural systems [2].

There is still no single definition of industrial ecology that is generally accepted. However, most definitions comprise similar attributes with different emphases. These attributes include the following:

• a systems view of the interactions between industrial and ecological systems
• the study of material and energy flows and transformations
• a multidisciplinary approach
• an orientation toward the future
• a change from linear (open) processes to cyclical (closed) processes, so the waste from one industry is used as an input for another
• an effort to reduce the industrial systems' environmental impacts on ecological systems
• an emphasis on harmoniously integrating industrial activity into ecological systems
• the idea of making industrial systems emulate more efficient and sustainable natural systems
• the identification and comparison of industrial and natural systems hierarchies, which indicate areas of potential study and action .

\Table 1 depicts hierarchies of political, social, industrial, and ecological systems [3]. **Industrial ecology** Industrial ecology studies the interaction between different industrial systems as well as between industrial systems and ecological systems. The focus of study can be at different system levels.

The Institute of Social Ecology's definition of social ecology states that industrial ecology is the study of the interactions between industrial and ecological systems; consequently, it addresses the environmental effects on both the abiotic and biotic components of the ecosphere.

For example, acidification of freshwaters can in principle influence metal–organism interactions. The decrease in pH may affect **metal speciation** ; speciation (the evolutionary process by which new biological species arises **)** concerns the identification and quantification of specific forms of an element, e.g. the analysis of edible fish tissue to determine the concentrations of methylmercury and inorganic mercury present.

As different forms of an element may exhibit differing toxicities and nobilities in the environment, it is clearly of importance to be able to distinguish between the individual species present in a particular sample in solution; metal speciation may affect biological sensitivity at the level of the cell surface.

Table 1 Organizational hierarchies

Political Entities	**Social Organizations**	**Industrial Organizations**	**Industrial Systems**	**Ecological System**
UNEP	World population	ISO	Global human material and energy flows	Ecosphere
U.S.(EPA, DOE)	Cultures	Trade associations	Sectors (e.g., transportation or health care)	Biosphere
State of Michigan (Michigan DEO)	Communities	Corporations	Corporations/institutions	Bio geographical Region
Washtenaw county	Product systems	Divisions	Product systems	Biome landscape
City of Ann Arbor	Households	Product development teams	Life cycle stages	Ecosystem
Individual Voter	Individuals/ Consumers	Individuals	Life cycle unit steps	Organism

Environmental acidification (pH 7–4) can have possible effects on (1) metal speciation in solution, (2) metal adsorption at biological surfaces, and (3) metal uptake by and toxicity to aquatic biota.

Attention was focused on some 10 metals of potential concern in the context of freshwater acidification (Ag, Al, Cd, Co, Cu, Hg, Mn, Ni, Pb, Zn). For the four metals (Al, Cu, Hg, Pb) predicted to manifest speciation changes in the range pH 7–4, confirmatory experimental data are available for two (Cu, Pb). In the six remaining cases predicted to show little sensitivity to pH changes in this range, supporting experimental evidence exists for four metals (Ag, Cd, Mn, Zn).

A pH-dependent biological response is documented over a realistic range of H^+ and metal concentrations for six of the 10 metals considered (Al, Cd, Cu, Zn and, to a lesser extent, Hg and Pb). These six metals fall into two groups: those for which a decrease in pH results in a decreased biological response (type I behavior: Cd, Cu, Zn) and those for which the dominant effect of acidification is to increase metal availability (type II behavior: Pb). Data for the remaining two metals (Al, Hg) clearly reveal pH effects, but the results are too few and too inconsistent to allow generalizations ([4],[5]).

There are many textbooks that introduce ecological concepts and principles ([6],[7],[8]).

2. GOALS OF INDUSTRIAL ECOLOGY

The primary goal of industrial ecology is to promote sustainable development at the global, regional, and local levels **[9].** Sustainable development has been defined by the United Nations World Commission on Environment and Development as “meeting the needs of the present generation without sacrificing the needs of future generations”**[10].** Key principles inherent to sustainable development include: the sustainable use of resources, preserving ecological and human health (e.g. the maintenance of the structure and function of ecosystems), and the promotion of environmental equity (both intergenerational and inter societal) [11].

3. MATERIAL AND ENERGY FLOWS AND TRANSFORMATIONS

A primary concept of industrial ecology is the study of material and energy flows and their transformation into products, byproducts, and wastes, throughout industrial systems. The consumption of resources is inventoried along with environmental releases to air, water, land, and biota. Figures 2, 3, and 4 are examples of such material flow diagrams.

To identify areas to target for reduction, one must understand the dissipation of materials and energy (in the form of pollutants) – how these flows intersect, interact, and affect natural system. Distinguishing between natural material and energy flows and anthropogenic flows can be useful in identifying the scope of human-induced impacts and changes.

As is apparent in Table 2, the anthropogenic sources of some materials in natural ecosystems are much greater than in natural sources.

Tables 3, 4 and 5 provide a good example of how various materials flow through one product system, that of the automobile.

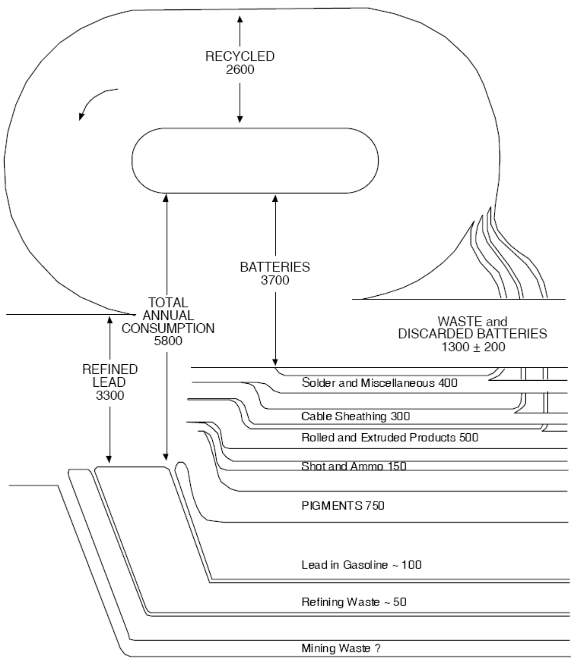

Figure 2 World extraction, use, and disposal flow of lead (thousand tons, 1990) [12]

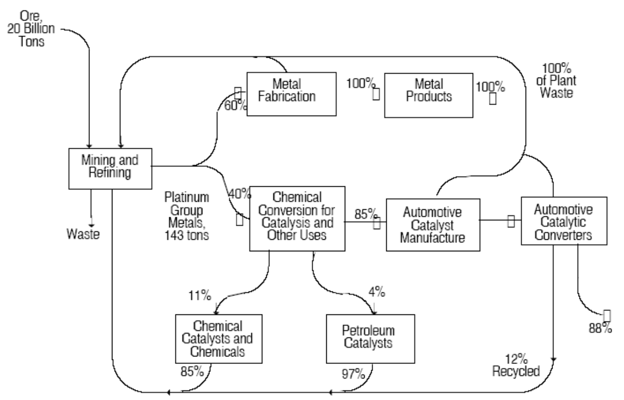

Figure 3 Flow of platinum through various product systems [13]

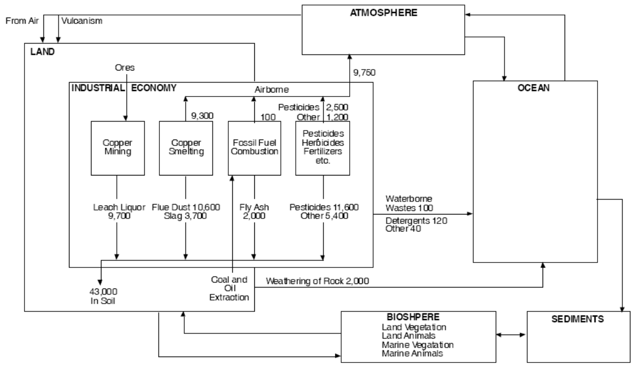

Figure 4 Simplified representation of arsenic pathways in the U.S (metric tons) [14]

Table 2 Worldwide atmospheric emissions of trace metals (thousand tones/year) [15]

Element	Energy Production	Smelting, refining, and mining	Manufacturing processes	Commercial uses, incineration, and transit	Total anthropogenic contributions	Total contributions by natural activities
Antimony	1.3	1.5	-	0.7	3.5	2.6
Arsenic	2.2	12.4	2.0	2.3	19.0	12.0
Cadmium	0.8	5.4	0.6	0.8	7.6	1.4
Chromium	12.7	-	17.0	0.8	31.0	43.0
Copper	8.0	23.6	2.0	1.6	35.0	28.0
Lead	12.7	49.1	15.7	245.0	332.0	12.0
Manganese	12.1	3.2	14.7	8.3	38.0	317.0
Mercury	2.3	0.1	-	1.2	3.6	2..5
Nickel	42.0	4.8	4.5	0.4	52.0	29.0
Selenium	3.9	2.3	-	0.1	6..3	10.0
Thallium	1.1	-	4.0	-	5.1	-
Tin	3..3	1.1	-	0.8	5.1	-
Vanadium	84.0	0.1	0.7	1.2	86.0	28.0
Zinc	16.8	72.5	33.4	9.2	132.0	45.0

Table 3 Global flows of selected materials[16]

Material	Flow (Million metric tons/yr)	Per-capita flow*
Minerals		1.2**
Phosphate	120	
Salt	190	
Mica	280	
Cement	890	
Metals		0.3
Al	0.97.0	
Cu	8.5	
Pb	3.4	
Ni	0.8	
Sn	0.2	
Zn	7.0	
Steel	780	
Fossils Fuels	1.6	
Coal	3.200	
Lignite	1.200	
Oil	2.800	
Gas	9.20	
Water	41,000.00	8,200.0

** Per –capita figures are based on a population of five billion people and include materials in addition to those highlighted in this table.*
*** Does not include the amount of overburden and mine waste involved in mineral production; neglects sand, gravel, and similar material but includes cement [17].*

The evolution of the industrial system from a linear system, where resources are consumed and damaging wastes are dissipated into the environment, to a more closed system, like that of ecological systems, is a central concept to industrial ecology. Braden Allenby has described this change as the evolution from a Type I to a Type III system, as shown in Figure 5.

Table 4 Resources used in automobile manufacturing [18]

Plastics use in cars, vans and small trucks-millions of pou			
Material	**U.S.Auto**	**All U.S.**	**Percent of total**
Nylon	141	595	23.7
Polyacetal	25	141	17.7
ABS	197	1,243	15.8
Polyurethane	509	3,245	15.7
Unsat PE	192	1,325	14.5
Polycarbonate	50	622	8.0
Acrylic	31	739	4.2

Polypropylene	298	7,246	4.1
PVC	187	8,307	2.3
TP PE	46	2,101	2.2
Polyethylene	130	18,751	0.7
Phenol	19	3,162	0.6

Table 5 Metals used in automobile manufacturing

Other resources-as percentage of Total U.S. consumption (1988)	
Material	**Percentage of total**
Lead	67.3
Alloy steel	10.7
Stainless steel	12.3
Total steel	23.0
Aluminum	18.3
Copper and copper alloys	10.2
Malleable iron	63.8
Platinum	39.1
Natural rubber	76.6
Synthetic rubber	50.1
Zinc	23.0

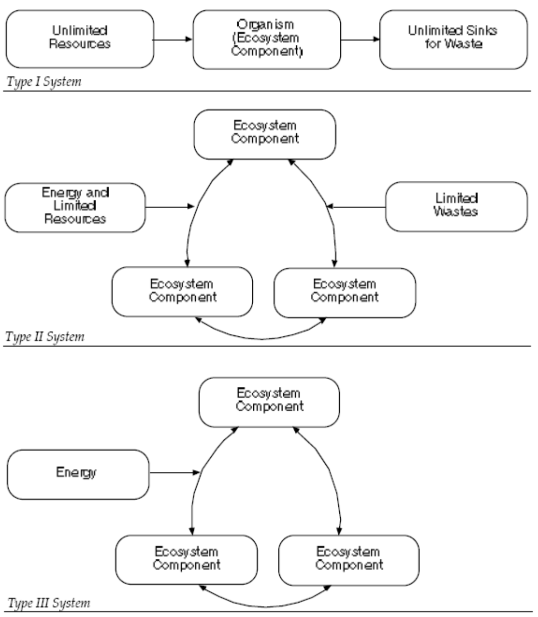

Figure 5 System types [19]

4. CONCLUSIONS

Traditionally, increase of industrial activity has automatically meant in increased load on the environment in an almost straight line relationship. By carefully selecting the processes and the combination of industries, future industrial complexes need in theory not cause any pollution of the environment at all. Although this obviously is an ideal situation which in reality is impossible to achieve, it may be a good and challenging planning assumption. Because human health is dependent on the health of the other components of the ecosystem, ecosystem structure and function should be a focus of industrial ecology. It is important that industrial activities do not cause catastrophic disruptions to ecosystems or slowly degrade their structure and function, jeopardizing the planet's life support system. Industrial ecology can be taught as a separate course or incorporated into existing courses in schools of engineering, business, public health and natural resources.

Due to the multidisciplinary nature of environmental problems, the course can also be a multidisciplinary offering; the sample syllabi offered in this compendium illustrate this idea. Degrees in industrial ecology might be awarded by universities in the future.

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