The Best of Both Worlds:

A Beginner's Guide to Industrial Ecology

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Imagine a future of near-infinite resources, when the Earth's human population has recognized the trauma it has caused the natural environment and responded by stabilizing its population, industrial systems fit seamlessly into natural ones without leaving irreparable gashes through indiscriminate extraction and emission, the concept of a landfill is economically and socially abhorrent, and all human activity is powered solely by daily solar radiation. This utopian vision appears irrelevant aside from its service as the backdrop for science fiction epics. Yet a growing number of forward-thinking scientists, engineers, entrepreneurs, academics, and policymakers who represent the newly created field of Industrial Ecology are pursuing this vision as the only viable positive end result of our civilization, if not our species and the rest of the ecosystem.

What is Industrial Ecology?

Industrial Ecology (IE) initially appears to be a tragic oxymoron. How can the interests of both industry and ecology be met simultaneously? Industry has developed over the last three centuries by systematically exploiting and suppressing the natural world, as wells as sacrificing environmental resilience for economic interests, while ecology often lambastes human endeavors for their environmental impact without acknowledging their social benefits. A solution to both the cognitive dissonance associated with the term IE and the interests of the two parties lies in the reexamination of human socio-industrial systems in the broader context of ecological systems, flows, and cycles.

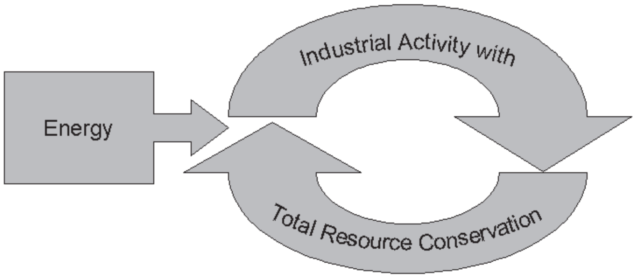
There has been a great deal of controversy within IE itself pertaining to the formulation of a mission statement and a pithy definition. Due to the vast and still-broadening range of interests represented in IE, it is difficult to precisely identify the field boundaries. Nevertheless, Industrial Ecologist Matthias Ruth stated in 1998: "The emerging discipline of industrial ecology is an attempt to (re)establish an intricate mesh of exchanges of goods and services in order to minimize environmental impacts of economic activities. To achieve these goals, industrial ecology must concentrate not only on the role of products, technology, and industry, but also on the combined socioeconomic and environmental system.[1]" This broad definition highlights five main elements that distinguish the importance of IE.

The Structure of Industrial Systems

A central idea in IE is to close loops in anthropogenic resource and energy flows (Fernandez J, lecture, Spring 2006). Illustrated in Fig. 1, models of industrial systems range from wasteful to conservationist. A Type I ecology, exemplified by mid-twentieth century industry in the developed world, pays little attention to scarcity issues on either the source or sink side; resources are cheap, essentially infinite, and there is plenty of room for, and few restrictions on, waste disposal. Therefore, resources are used once and then disposed of. A Type II ecology, to which the developed world is slowly moving, is a natural progression from a Type I ecology that exists in a finite environment for an extended period of time. In this industrial ecology, economic pressures from scarcity and regulations put limitations on the sources and sinks for resources, promoting modest loops in industry. However, a Type II ecology is not an equilibrium state; only economic and regulatory pressures prevent its reversion to a Type I ecology. That is why Industrial Ecologists advocate a full transformation to a Type III ecology. In this system, material

Type I Industrial Ecology

Type II Industrial Ecology



Type III Industrial Ecology

Figure 1: The three types of Industrial Ecologies. Industrial Ecologists advocate closing loops in industry to transition from a Type I ecology to a Type III ecology.

Figure 2: The three types of Industrial Ecologies. Industrial Ecologists advocate closing loops in industry to transition from a Type I ecology to a Type III ecology.

and energy recycling endeavors are at thermodynamic maxima, and only minimal resource and solar energy inputs are necessary to sustain system vitality. Unfortunately, the transition to such an industrial structure is as much a socioeconomic issue as it is a technological one.

The Environment Analogy

The natural environment is a resilient, self-regulating, productive system. IE utilizes this 4.5 billion-year-old system as a model for the re-engineering of the human industrial complex. The environmental analogy provides many guidelines for industrial organization, from justification for a closed-loop system to an inspiration for new elements that should be introduced to industry to increase efficiency and resilience. An example of the latter is a call by Côté to increase "industrial biodiversity.[2]" He claims that the development of industrial equivalents of "scavengers and decomposers" is central to the development of a Type III ecology, as fundamental units produced by such ecological elements will not only help lubricate the large material flow recycling, but also allow for small-to-medium scale recycling projects to become economical.

The Environmental Footprint

The concept of an environmental footprint is not unique to IE. However, in IE, a standardized method of calculating and interpreting environmental impacts has become a useful metric in technical decision making. This concept is important as a tool to communicate with economists on their own terms. Goals and methods of IE often do not stand up to economic criticism because misguided attempts by the latter to apply a human construct to nature yield inconsistent results. The placement of anthropogenic environmental impact into standardized, scarce units is a step towards the quantification of abstract environmental qualities[3]. Wackernagel developed a unit in an attempt to understand the overshoot between global consumption and natural production[4]. His footprint quiz can be found online at www.myfootprint.org.

The Role of Technology

Many Industrial Ecologists believe technology and innovation to be the keys to survival. Technology is the object of especially high expectation because it integrates mainstream economics with IE[5]. In IE, technology is measured by appropriateness, and so technology for one application—capturing solar energy—can range from the ultra-high-tech thin film photovoltaic cell to the low-tech solar cooker, depending on regional resource capacities. The importance of technology is explained through what many consider to be the central equation of IE, the IPAT equation. In this thought equation, the environmental impact of some system resource is equal to the product of population P, affluence of the population A (or, resource intensity per capita), and impact per resource T (technology). It is generally accepted that the first two terms, P and A, will increase due to humanity's drive for success. Therefore, less impactful technologies must be developed in order to prevent irreversible harm to the environment[6]. An easy example of the application of the IPAT equation is the automobile. In order to see no change in impact of the American automobile fleet ($I=0$), a balance must be struck between the increasing size of the fleet ($P>1$) and increasing luxury of each automobile ($A>1$) with a technological advancement of the fleet ($T<<1$), namely, increased fuel efficiency.

The Inclusion of the Socioeconomic System

Finally, the inclusion of the socioeconomic system in Ruth's definition indicates the field has matured out of its naive early environmental ideologies to become one that desires a balance among socioeconomic, industrial, and environmental interests. As the spheres of sustainable development and IE grew and impinged on one another, it became obvious that the goals of the two fields were complementary. Unlike environmental ecology, in which structures of organisms are predictable and equitable, so evolved for the survival of the species, human social constructs are more complicated, and are not designed to strengthen the species against competing natural interests. The obfuscated intentions of socioeconomic systems make their inclusion in the discussion for the survival of the human species paramount (Fernandez J, lecture, Spring 2007).

History of Industrial Ecology

The official beginnings of Industrial Ecology as a field of study can be traced to a Scientific American article published in 1989 by Frosch and Gallopoulos called "Strategies for Manufacturing." This paper presented ideas of an "industrial ecosystem" and closed-loop manufacturing, spurring a flurry of follow-up research that became the subject of a 1992 National Academy of Sciences (NAS) symposium[7]. However, Frosch and Gallopoulos were not totally groundbreaking, as a significant body of research expressing similar ideas existed before them. In the 1960s, Jay Forrester started describing the world as a "series of interwoven systems.[8]" During the next three decades, a number of remarkable individuals introduced the fundamentals of IE to the general body of knowledge. Rachel Carson and Eugene Odom expressed the ecological perspective, while Donella Meadows and Amory Lovins stressed the economic and social benefits of industrial efficiency (Fernandez J, lecture, Spring 2007). By the NAS symposium in 1992, representatives from many academic backgrounds had written papers on the subject of IE.

In 1997, the first issue of the Journal of Industrial Ecology was released, heralding the arrival of the new scientific field to mainstream academia. Since then, a professional society has been founded (International Society for Industrial Ecology), a second journal created (Progress in Industrial Ecology), and postgraduate programs established at universities worldwide.[9]

The current state of Industrial Ecology

IE currently focuses on the development of two interrelated areas, analysis and design (Fernandez, lecture, Spring 2007). The former is concerned primarily with mapping resource consumption at various system boundaries. There are a number of theoretical elements in IE analysis:

- Physical accounting[10]: determination of resource stocks and flows across statistically relevant system boundaries;
- Natural capital[11]: a view of the ecosystem as a means for production; analogous to a supply of money used often for infrastructure investment;
- Ecological economics[12]: a view of economics that relates economic theory to natural behaviors; and
- Systems complexity[13]: a way of making generalities about the natural ecosystem in order to divine governing mechanisms.

In addition to these theoretical elements, IE analysts utilize a varied set of unique tools and methods:

- Life Cycle Assessment (LCA)[14]: aggregation of all materials and costs that go into a product or process in order to gain a full understanding of the impact of a particular technical decision;
- IPAT equation[15]: used to identify necessity for technological improvement (see above);
- Resource metrics[16]: energy, emergy, and exergy are properties of pieces in a system that can be measured and optimized; and
- Environmental footprint: see above.

The second area in current IE is design. The applied branch of IE relies very heavily on the analysis tools listed above, but also guides the analysis by being active in the evolution of the field. Some guiding principles for IE engineering have been identified:

- Dematerialization[17]: the quest to achieve the same service for less resources;
- Green chemistry[18]: a reduction in the use and production of pollution and toxins in industry;
- Distributed energy[19]: development of methods for small-scale, site-appropriate, resilient power generation facilities; and
- Closing loops[20]: finding uses for waste flows from industrial processes or re-engineering material processes to generate usable waste and recyclable products.

IE engineers and policymakers have devised some methods to facilitate the development and adoption of the above goals[21]:

- Extended Producer Responsibility: a move to give the producer the life-cycle responsibility for its products, incentivizing environmentally benign design and manufacturing;
- Design for Environment: initiative to promote design philosophies that prevent pollution while being cost-effective and scientifically innovative; and
- Design for Disassembly: a push for products and materials that can be either quickly torn down to reusable fundamentals or easily recycled without major loss of functionality.

Themes and tools identifying today's IE agenda are constantly in flux as new interests enter the IE sphere of influence and new problems arise to be solved. The above lists offer just a sampling of IE theory and methods.

What does the future hold?

The future of IE is unclear. While all signs point towards the increasing importance of IE concepts and tools, it is unknown if the current broadening the field is undergoing will result in the continued existence of a separate field or its dissolution. It is possible that the role of the Industrial Ecologist will become so crucial to the continued survival of the human race that other disciplines will simply adopt the principles of IE into their own mainstream priorities (Fernandez J, lecture, Spring 2007). Nevertheless, as environmental issues become major driving forces, particularly with respect to global warming, the density of relevant knowledge residing under the auspices of IE will most likely likely result in a continued expansion of academic programs, policy initiatives, and engineering firms to accommodate the growing demand.

Industrial Ecology at MIT

If you are interested in pursuing IE while at MIT, there are a number of courses and research opportunities across the institute. There are three courses in the Spring 2007 MIT Subject Listing and Schedule[22] that use the phrase "Industrial Ecology" in their subject descriptions: 1.184J/3.560J/ESD.123J Industrial Ecology, 4.406 Ecologies of Construction, and 2.813/2.83 Environmentally Benign Design and Manufacturing. These three classes each approach IE slightly differently, with 3.560J taking a materials approach that focuses on LCA, 2.813 looking at the broader manufacturing picture, and 4.406 concentrating on the built environment. There are many other classes that teach the tools and ideas upon which IE is built; a list of these is omitted for fear of incompleteness. However, databases such as Energyclasses[23] and Enviroclasses[24] can be very helpful in identifying relevant courses—at this issue's publication, almost every MIT academic program is represented in one of these two databases.

Another great way to become involved with IE at MIT is through UROPs and research. The Laboratory for Energy and the Environment[25], the Center for Technology, Policy, and Industrial Development[26], the Building Technology Program[27], and the Laboratory for Manufacturing and Productivity[28] are all large research groups that deal with IE issues.

Finally, the most effective and enriching way to get involved with Industrial Ecology is to join or start a student group. Many existing groups can be easily found by searching the MIT homepage. The first industrial revolution, while occurring rapidly, required a slow evolution of decentralized innovation to bring the world to a place where rapid change could occur. We can see the outline of a second industrial revolution up ahead—a luxury of foresight that 17th century Europeans lacked when developing cottage industries and mining coal for its prodigious energy content—but in order to reach the point where the IE utopia is within reach, creative, passionate people must take the initiative. There are few better places on the planet for such a revolution to take hold as MIT.

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