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2011 "Industrial Ecology." In Oladele Ogunseitan ed., *Green Health: An A-Z Guide, Volume 9,* Paul Robbins ed., *The SAGE Reference Series on Green Society: Toward a Sustainable Future-Series*. SAGE Publications. Series Description: http://www.sagepub.com/books/Book233878?seriesId=Series1216

Industrial Ecology

Industrial Ecology begins with the examination of the interconnections both within and between industrial and ecological systems. Seeking to transform current industrial processes from linear to cyclical systems, industrial ecology is rooted in the notion that structuring industrial systems to behave as ecosystems do would create sustainable development—where the wastes and byproducts created within one system are utilized as energy or raw materials for another system. Just as the death and decay of plant matter provides the nutrients to create rich, fertile soil, the waste and byproducts from one industrial process can become the energy and raw materials to fuel another industrial process.

The basic principles of industrial ecology include:

- Modeling technological and industrial systems after ecological systems
- Reducing the negative impacts of technology on the environment
- Fostering sustainable technological and societal development
- Using a holistic approach to view environmental problems
- Identifying and tracing flows of energy and materials through various systems

An emergent, interdisciplinary field, industrial ecology draws from subjects as diverse as law, economics, business, public health, natural resources, ecology, and engineering. The roots of industrial ecology reach back to the 1950s and '60s system dynamics work of Jay Forrester, one of the first researchers to define the world as a collection of interconnected systems. Though Forrester's system dynamics work was first used to address corporate management problems, by the 1970s this framework for viewing human interactions had spawned works that focused on environmental degradation and the lack of sustainability of the industrial system. Building on this early systems analysis work, Robert Ayres, in 1989, put forth the concept of "industrial metabolism"—a framework for studying how energy and materials flow through various systems. That same year, a *Scientific American* article written by Robert Frosch and Nicholas Gallopoulos introduced the idea of *industrial ecosystems*, and soon the term "industrial ecology" entered the lexicon. And so while Forrester's early work was born of efforts to analyze and address very specific social systems—management and employees—his pioneering of system dynamics lies at the heart of industrial ecology and its ideas regarding the relationship between industrial and natural ecosystems. This correlation between industrial and natural ecosystems is essential to industrial ecology.

The 1990s saw further development in the subject of industrial ecology, with the National Academy of Science holding its Colloquium on Industrial Ecology in 1991. This is considered by many to have marked a turning point for how industrial ecology was to be interpreted and embraced as a field of study, not just by academia, but by industry and government as well. 1994's *The Greening of Industrial Ecosystems*, edited by Braden Allenby and Deanna Richards and published by the National Academy of Engineering,

further nurtured the growth of industrial ecology by exploring and defining its core concepts and applications. Beyond examining the implications for industry and the environment, the work also explains how industrial ecology crosses into law, economics, and public policy. By the late 1990s, *The Journal of Industrial Ecology* was in publication, and in 2000, The International Society for Industrial Ecology was formed. Norwegian University of Science and Technology offered the first degree program for industrial ecology in the mid-1990s, and today, dozens of other colleges and universities offer degrees, graduate certificate programs, and coursework linked to industrial ecology.

An example of industrial ecology in action is Denmark's Kalundborg industrial park, where the participating businesses are integrated to function in a symbiotic manner and where waste and byproducts are minimized by finding other uses for them. Here, the excess heat generated by industrial processes is utilized for fish farming, heating of nearby homes, and greenhouse agriculture. Further, as just one example of the way that this industrial park repurposes waste and byproducts, the Asnaes Power Station produces gypsum as a byproduct of the electricity generation process, and this gypsum then becomes a resource for Gyproc, which produces plasterboards. Thus, just as ecosystems are closed-loop systems which produce no waste, the Kalundborg industrial park has moved from linear-based production systems to circular systems in which waste and byproducts become useful materials for other processes.

Some of what the Kalundborg industrial park has achieved includes:

- Significant reductions of the consumption of energy and resources such as coal, oil, and water
- Reduction of harmful emissions and reduced volumes of effluent water
- Conversion of traditional waste products into raw materials for production

The success of the Kalundborg industrial park is tied to Kalundborg's embracing of industrial ecology's central tenets, including Ayres's idea of *industrial metabolism*, which is the process of identifying and tracing flows of energy and materials through various systems. By analyzing material and energy flows and changes, negative impacts on the natural ecosystem can be minimized, and resource efficiency can be maximized. Also important to Kalundborg's success, and to any entity practicing industrial ecology, is a focus on the entire life-cycle of products, processes, and services. This life-cycle assessment (LCA) is key to understanding the environmental aspects of, and potential impacts associated with, a product, process, or service. Predicated upon an evaluation of the environmental burdens associated with a product, process, or activity, LCA is achieved by identifying the energy and materials used by a system as well as the resultant wastes released to the environment. In this way, LCA can be instrumental in the creation of strategies to affect not just environmental efficacy but also industrial efficiency.

Closely linked to industrial ecology is the concept of a *circular economy*, which seeks to balance economic development with environmental and resource protection. Most

concretely embraced in China, where, in 2008, the Circular Economy Promotion Law was passed, a circular economy is achieved by interlinking manufacturing and service businesses. In this way, economic performance is enhanced and environmental impacts are minimized through collaborative efforts to manage environmental and resource issues. This level of industrial symbiosis exemplifies how concepts of industrial ecology can affect the domain of politics and economics.

Industrial ecology's impact on environmental and industrial policies is more readily observed elsewhere in the developed world than in the United States. For example, the European Union has proposed an Integrated Product Policy (IPP), which is intended to increase demand for green products while encouraging green design and manufacturing processes. In resource-limited Japan, extensive product recycling and energy efficiency have been embraced to counter decades of environmental degradation and resource exhaustion. In line with an eco-industrial approach to achieving sustainable development, Japanese leaders have initiated various types of eco-industrial projects throughout the country.

Driven by a desire both to foster sustainable development and to increase manufacturing efficiency, this international shift in the ways that resources are managed and industry is structured has deep implications for the United States. Today's global economy means that industrial ecology principals are being applied to some of the products, processes, and services created and used by international firms with whom the United States does business. Beyond the way these changes may impact regulatory obligations and trade issues, the United States, whose approach to environmental policy has rested on the evaluation of competing scientific claims and heated, often litigious debate, may approach industrial ecology policies in a different way than has Europe or Japan. Further, it remains to be seen how the principals of industrial ecology may be applied to information technology and to the technological infrastructure that undergirds much of the US economy.

While the United States has not yet displayed the same readiness to accept and apply industrial ecology principals as have some other nations, there do exist examples of industrial ecology in action within US borders. Here, the Environmental Protection Agency has been researching and exploring ways to apply industrial ecology concepts, the National Pollution Prevention Center for Higher Education now uses systems analysis to develop pollution prevention educational materials, and the National Science Foundation supports research related to industrial ecology. California's Department of Toxic Substance Control has spearheaded a Green Chemistry initiative, and in the corporate world, AT&T funds an Industrial Ecology Faculty Fellowship program, and Natural Logic, a US-based consulting firm that has worked with dozens of clients, including Levi Straus, Sara Lee, and Rhino Records, provides guidance to firms who are seeking to apply ecological theory to industrial methods.

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Still, in order for industrial ecology to truly impact environmental, technological, and economic policy, a rigorous scientific foundation will be essential. Theories, models, research, and experiments are needed to test and advance industrial ecology's assumptions. In order to further develop industrial ecology in the United States and elsewhere, continued research is called for in order to provide a robust framework for understanding how technology and the environment interact with each other. By focusing on environmental, industrial, economic, and human health, industrial ecology is poised to usher in a new age of sustainability. In order to bring this to fruition, industrial ecology needs to further develop as a field, and this can be achieved by strengthening its framework in these ways: clarifying industrial ecology's definition, scope, and goals; examining more intently the relationship between industrial ecosystems and natural ecosystems; fleshing out the definition of "sustainable development"; fostering deeper interdisciplinary collaboration; expanding industrial ecology-focused curriculum development in colleges and universities; refining tools such as the life cycle assessment; and implementing government policies that encourage industry to take seriously its role in stewardship of resources and the environment.

See Also: Education and Green Health; Government Role in Green Health; Green Chemistry; International Policies; Private Industry Role in Green Health; U.S. Environmental Protection Agency

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