Pollution Prevention and Industrial Ecology
NATIONAL POLLUTION PREVENTION CENTER FOR HIGHER EDUCATION

Industrial Ecology Annotated Bibliography

Annotations written by the U.S. Environmental Protection Agency Futures Group; Ernest Lowe, Indigo Development; and Andy Garner, NPPC research assistant.

Allen, David. "Using Wastes as Raw Materials: Opportunities to Create an Industrial Ecology." *Hazardous Waste & Hazardous Materials* 10, no. 3 (Summer 1993): 273-277.

Developing an understanding of Industrial Ecology (IE) and implementing Design for Environment (DfE) requires a sophisticated understanding of waste streams and the processes and products that generate them. Data deficiencies and methodological issues complicate this necessary effort. Allen demonstrates how data on industrial and municipal wastes can be used to assess the potential utility of waste streams as raw materials. He also briefly examines case studies of lead, cadmium, and chromium waste flows and provides useful waste flow diagrams.

Allenby, Braden R. "Achieving Sustainable Development Through Industrial Ecology." *International Environmental Affairs* 4, no. 1 (1992): 56–68.

In the first section, Allenby applies a "Type I, II, III" approach to show how our current industrial economic system is unsustainable. IE will help society reach the sustainable Type III level. Allenby includes useful diagrams of the Type III level. He emphasizes that IE must "subsume all human economic activity" and will require changes to all aspects of society. In the second section, Allenby emphasizes the need for "institutes of IE" and then outlines the main tasks and fundamental characteristics of these institutes.

———. "Integrating Environment And Technology: Design For Environment." In *The Greening of Industrial Ecosystems,* edited by Braden R. Allenby and Deanna J. Richards, 137–148. Washington: National Academy Press, 1994.

Design for Environment (DfE) is the first attempt directly based on IE principles to create a systems-based, multi-dimensional methodology to incorporate environmental constraints and considerations into the design process. Allenby gives a useful overview of the key elements of DfE and how to implement them, and then provides a DfE test case based on options for lead solder use in electronics. Allenby also creates a matrix system for DfE applications and provides diagrams to use with the matrix.

Allenby, Braden R., and Deanna J. Richards. *The Greening of Industrial Ecosystems.* Washington: National Academy Press, 1994.

A collection of articles that build on earlier conceptual work on industrial ecology. The works strive to develop the context of industrial ecology with chapters on energy, wastes, pollution prevention, law, economics, and the role of government, along with giving examples where aspects of industrial ecology are already emerging such as in the auto industry and telecommunications. The book concludes by identifying future roles of universities and institutes; it also details areas where research efforts are needed.

Ayres, Robert. U. "Toxic Heavy Metals: Materials Cycle Optimization." *Proceedings of the National Academy of Sciences, USA* 89 (February 1992): 815–820.

Ayres uses the case of the toxic heavy metals to show that long-term ecological sustainability is incompatible with an open materials cycle. He proposes a system of materials cycle optimization whereby the materials cycle is closed by accomplishing: (1) banning or discouraging dissipative uses of toxic heavy metals, and (2) increasing recycling of materials that are not replaceable in principle. Ayres also includes a very useful diagram of the current material-process flow.

Beer, Stafford. *Platform for Change.* New York: John Wiley,1980.

———. *Brain of the Firm*. 2d ed. New York: John Wiley, 1981.

———. *The Heart of Enterprise*. New York: John Wiley, 1979.

Beer's Viable System Model offers a dynamic organizational structure grounded in the understanding that organizations are living systems interacting with larger living systems. It is a vital tool for managing the transition to industrial ecology.

Callenbach, Ernest, Fritjof Capra, and Sandra Marburg. *Ecomanagement: The Elmwood Guide to Ecological Auditing and Sustainable Business.* San Francisco: Berrett-Koehler, 1993.

This survey and workbook is valuable for its systemic integration of the technical and organizational auditing of a business's ecological performance.

Canadian Institute of Chartered Accountants. "Accounting and the Environment: Unearthing the Answers." A special issue of *CA Magazine* 124 (March 1991): 16-50.

Papers contribute to the rethinking of accounting/auditing practices, including accounting models that reflect environmental costs, revision of standards, tax incentives, ethical analysis, and a survey of approaches to eco-auditing.

Commoner, Barry. *Making Peace With the Planet*. New York: Pantheon Books, 1990.

"Science and politics, the private sector and public policy, the right to consume and the price of that right—all of these issues must be dealt with together."

Dillon, Patricia S. "Implications of Industrial Ecology for Firms." In *The Greening of Industrial Ecosystems,* edited by Braden R. Allenby and Deanna J. Richards, 201–207. Washington: National Academy Press, 1994.

Implementation of advance environmental practices requires more than generation of data; it requires that the business and capital planning of a firm, and its organizational structure, be such that the data can be acted upon. Dillon outlines some common and successful features of company product responsibility programs and identifies future challenges to this process.

Duchin, Faye. "Input-Output Analysis and Industrial Ecology." In *Greening of Industrial Ecosystems,* edited by Braden R. Allenby and Deanna J. Richards, 61–68. Washington: National Academy Press, 1994.

Natural, systems-based input-output models of economic activity (capable of sophisticated but well-understood mathematical manipulation) can be important resources as IE principles are implemented. Work along these lines is already underway.

Durning, Alan. *Asking How Much Is Enough.* Washington: World Watch Institute,1991.

Valuable exploration of the transition from "the consuming society" to "a culture of permanence."

Frosch, Robert A. "Industrial Ecology: A Philosophical Introduction." *Proceedings of the National Academy of Sciences, USA* 89 (February 1992).

Frosch first parallels the industrial ecology system with the natural ecosystem to emphasize that IE would maximize the economical and efficient use of waste materials and products at the end of their lives as inputs to other processes and industries. (Like many other scholars, he is applying IE to the production process.) He focuses on the waste end of the production process and outlines several issues that must be addressed, especially the importance of the environmentally sound design of wastes and how that affects the design of products and processes.

Frosch, Robert A., and Nicholas E. Gallopoulos. "Strategies for Manufacturing." *Scientific American* 261 (September 1989): 144–152.

The authors first describe the current global environmental crisis to emphasize IE as a solution. Then they outline the fundamental elements of an industrial ecosystem, including new trends in manufacturing. Next, the authors discuss the workings and shortcomings of three industrial subsystems (iron / steel, petroleum / plastics, and platinum-group metals) to provide insight into how subsystems can be improved to develop an industrial ecosystem. The authors also discuss options for industrial and consumer waste-minimization. The article concludes with a discussion on the transition to and implementation of IE (barriers, solutions, etc).

———. "Towards an Industrial Ecology." In *The Treatment and Handling of Wastes,* edited by A.D. Bradshaw, et al. New York: Chapman & Hall (for the Royal Society), 1992.

The article begins with a discussion that outlines the need for an IE approach (i.e., resource depletion). Then the authors give a useful description of the IE concept, including the constraints to widespread implementation of IE practices. The authors examine three subsystems of the manufacturing network (iron, plastics, and platinum-group metals) to provide insight into what is lacking and how the ecosystem approach could help. The authors also include a section on byproducts and wastes in these subsystems and the consumer side of the problem. The article ends with a discussion of how improved economic, educational, and societal structure will be required to approach an ideal IE system.

Graedel, T.E., and B.R. Allenby. *Industrial Ecology*. Englewood Cliffs, NJ: Prentice Hall, 1995.

The first university textbook covering the subject that provides a comprehensive introduction to IE. The authors examine a wide range of perspectives within industrial ecology—societal, environmental, legal, and economic. It discusses life cycle assessment methodologies and provides a complete presentation of practical approaches to design for the environment. The authors also consider prospects for the future, encouraging thought about industry-environment relations on time scales of several generations. The book includes 85 student exercises and is an excellent educational resource for IE-related courses in engineering, business, policy, law and public health.

Gross, Neil. "The Green Giant? It May Be Japan." *Business Week* (February 24, 1992): 74-75.

Reports on Japan's marketing and R & D lead in a broad range of environmental technologies.

Gupta, M.P. Sushil. "Towards Designing an Information-Flow-Structure of Resource Wastes for National Planning." *Systems Research* 3, no. 3 (1988).

Independent work that relates to industrial metabolism, input-output work, and environmental information systems.

Hoffman, Robert, Bertram McInnis, and Harry Van Drunen. "An Overview of the Sustainable Development Demonstration Framework." Robberts Associates, 1988.

This paper describes a sophisticated conceptual framework for tracking multiple interactions among industrial, economic, social, and natural systems; it also covers methods and software for simulating these interactions. The authors' "Whatif" simulation program is a Mac II environment for running the Sustainable Development Demonstration Framework or for developing other models; they are developing a model for product life cycle analysis.

International Institute for Sustainable Development and Deloitte & Touche. *Business Strategy for Sustainable Development, Leadership and Accountability for the '90s.* Winnepeg: 1992.

A valuable guide for companies moving to more comprehensive environmental management. Includes sections on strategic choices, enhancing management systems, accountability and stakeholder relations, corporate reporting, and a model "sustainable development report."

Jelinski, L.W., T.E. Graedel, R. Laudise, D. McCall, and C.K.N. Patel. "Industrial Ecology: Concepts and Approaches." *Proceedings of the National Academy of Sciences, USA* 89 (February 1992): 793–797.

This paper served as an introduction to the conference. It gives a brief overview of the concept of IE and briefly describes the different sections of the proceedings and the basic elements of the papers in each section. At the end, the authors offer a synopsis of the conference, giving some useful adjectives to characterize industrial ecology.

Keoleian, Gregory A., and Dan Menerey. "Sustainable Development by Design: Review of Life Cycle Design and Related Approaches." *Air and Waste* (Journal of the Air and Waste Management Association) 44 (May 1994): 645–668.

To achieve a more sustainable system, environmental issues must be addressed in design; life cycle design (LCD), Design for Environment (DfE), and related initiatives based on product life cycle are emerging as systematic approaches. This review presents the LCD framework developed for the U.S. EPA. The future of LCD and sustainable development depends on education, government policy and regulations, and industry leadership, but fundamental changes in societal values and behavior will ultimately determine the fate of the planet's life support system.

Keoleian, Gregory A., Werner J. Glantschnig, and William McCann. "Life Cycle Design: AT&T Demonstration Project." *Proceedings of IEEE International Symposium on Electronics and Environment,* San Francisco, 2 May 1994. Piscataway, NJ: IEEE Service Center, 1994.

Researchers at the University of Michigan applied their life cycle design framework in a research project with Optical Imaging Systems (OIS). OIS is a U.S. manufacturer of high-performance, active-matrix liquid crystal displays, one of the leading flat panel display technologies. The study evaluated OIS's environmental management system and how environmental performance may impact competition in the industry. Metrics were developed to measure environmental performance in a factory simulation model. Strategies for improvement are recommended according to incremental, reengineering, and future approaches.

Kleiner, Art. "What Does It Mean to Be Green?" *Harvard Business Review* 69 (July–August 1991): 38–47.

The article focuses on three important questions Kleiner feels any company's environmental agenda should include: (1) What products should a company bring to market? (2) How much open disclosure of pollution and health information should companies support? (3) How can companies reduce waste at the source, and how can they engage in pollution prevention? The third and most relevant question is a discussion of the basic principles behind IE and how they can be implemented.

Klimisch, Richard L. "Designing the Modern Automobile for Recycling." In *The Greening of Industrial Ecosystems,* edited by Braden R. Allenby and Deanna J. Richards, 165–170. Washington: National Academy Press, 1994.

The article describes actions in the domestic automotive industry to increase the recycling rate of essentially all the metallic components of vehicles. Klimisch also gives a case study of Design for Disassembly in the German automotive industry. German car manufacturers will be required to take back their products post-consumer and refurbish, recycle or safely dispose of them. The case study furnishes a unique look at the effects on design practices, business planning and costing, and industrial organizations of such an "industrial-ecology-like" requirement.

Lowe, Ernest. "Industrial Ecology: An Organizing Framework for Environmental Management." *Total Quality Environmental Management* 3, no. 1 (Autumn 1993): 73–85.

This article provides a very good summary of all currently relevant issues/elements of IE. Lowe begins with a background section on IE and then explains the analogy between IE and natural systems. He also includes numerous examples of current IE initiatives. Lowe then gives very good explanations of the main tools for applying IE principles (e.g., DfE, industrial metabolism, etc.). The article ends with a brief discussion of the relationship between IE and TQM.

Lynch, Daniel R., and Charles E. Hutchinson. "Environmental Education." *Proceedings of the National Academy of Sciences, USA* 89 (February 1992): 864–867.

The authors stress the need for a new profession devoted to environmental matters. They outline the qualities of this new profession and present an example two-year education program to produce people capable of implementing successful environmental policy in the future. The authors also propose an environmental roundtable as a focal point for academic, industrial, governmental, and public discussion on environmental matters.

Meadows, Donella, Dennis Meadows, and Jorgen Randers. *Beyond the Limits: Confronting Global Collapse, Envisioning a Sustainable Future*. White River Junction,VT: Chelsea Green Publishers, 1992.

A sobering update of the global modeling published as Limits to Growth in 1972. The systems dynamics-based World3 model has evolved, and the global ecosystem has been even more degraded in the 20 years since. The authors project scenarios for sustainable development and for global collapse.

Patel, C. Kumar N. "Industrial Ecology." *Proceedings of the National Academy of Sciences, USA* 89 (February 1992): 798–799.

Patel outlines several of the most environmentally harmful aspects of the current industrial system. He proposes utilizing the "cradle-to-reincarnation" production philosophy (basically IE applied to the production process), calling for environmentally sound production processes, recycling of wastes, lowered impacts on the environment, etc. He also proposes an industry-university-government round-table to set the strategy and agenda for process.

Pavlik, Bruce M., et al. *Oaks of California*. Los Olivos, CA: Cachuma Press, 1992.

An excellent introduction to ecology through study of a specific type of ecosystem.

Snyder, Robert. "Companies Invent New Methods To Measure Enviro-Performance." *Environment Today* 3, no. 4 (May 1992).

This short article describes new corporate initiatives for measuring environmental performance / impacts. Snyder discusses several elements of this new type of grading (i.e., TQEM) and gives specific examples from industry.

Socolow, R., C. Andrews, F. Berkhout, and V. Thomas. *Industrial Ecology and Global Change.* New York: Cambridge University Press, 1994.

Focuses on how humankind can continue to industrialize without disrupting and destroying natural ecological systems. Directed toward readers who already have an understanding of the importance of this issue and consequently have the desire to participate in effectively implementing appropriate strategies. Five main sections discuss: (1) the industrialization of society, (2) the main natural systems cycles, (3) toxic chemicals in the environment, (4) industrial ecology in firms, and (5) policy-making in the context of industrial ecology. The articles address critical issues such as recycling, solar energy, chemicals in agriculture, industrial innovation, and international perspectives.

Stahel, Walter. "Product Life As A Variable: the Notion of Utilization." *Science and Public Policy* 13, no. 4 (August 1986): 196–203.

Reflecting his work at the Product Life Institute, Geneva. This work implies a transition from manufacturing per se to interlinked manufacturing of highly durable products and continuing service as a mode of business.

———. "The Utilization-Focused Service Economy: Resource Efficiency and Product-Life Extension." In *The Greening of Industrial Ecosystems,* edited by Braden R. Allenby and Deanna J. Richards, 178–190. Washington: National Academy Press, 1994.

"Resource efficiency" and "product-life extension" are terms developed in Europe to describe a consumer economy based on the replacement of the Industrial Revolution product-oriented materials dispersion economy with a utilization-oriented product-life extension service economy, where funtionality, not physical goods, are the principle commodity. Stahel discusses the two types of closed-loop production systems for waste minimization that will lead to sustainable development: (1) reuse of goods and (2) recycling of goods. Stahel favors reuse over recycling as a process that results in a more long-term and environmentally beneficial utilization / optimizaton of goods.

Starr, Chauncey. "Education For Industrial Ecology." *Proceedings of the National Academy of Sciences, USA* 89 (February 1992): 868–869.

Starr believes that industrial ecology will require broadly educated engineers who can integrate their technology with the social, political, environmental, and economic aspects of its applications. He sees a new era for engineering education as engineers will have to take into account the end-use, obsolescence, and disposition of technological products under the IE framework.

Tibbs, Hardin. "Industrial Ecology—An Agenda for Environmental Management." *Pollution Prevention Review* 2, no 2 (Spring 1992).

The best overview of work in industrial ecology through mid-1991. An updated version of Tibbs' paper can be found in *Whole Earth Review* 77 (Winter 1992): 4–19.

Todd, Nancy and John. *Bioshelters, Ocean Arks, City Farming: Ecology as the Basis of Design.* San Francisco: Sierra Club Books, 1984.

The Todd's work in biological design at New Alchemy Institute provides a powerful parallel understanding of many themes in industrial ecology.

Todd, Rebecca. "Zero-Loss Environmental Accounting Systems." In *The Greening of Industrial Ecosystems,* edited by Braden R. Allenby and Deanna J. Richards, 191–200. Washington: National Academy Press, 1994.

Implementation of advanced environmental practices, such as DfE/IE, requires that management receive accurate information on costs created and avoidedby various options. This does not happen under current accounting systems, where environmentally related expenditures are frequently lumped into overhead. Todd advocates a zero-loss environmental information accounting, control, and accountability system, which will (1) record and monitor the flow and disposition of all inputs and (2) take into account all costs in the production process.

U.S. Congress, Office of Technology Assessment. "Biopolymers: Making Materials Nature's Way." September 1993. #PB94-107638.

Comprehensive background paper on the potential for substituting biologically based materials for many polluting, chemically based polymers.

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The mission of the NPPC is to promote sustainable development by educating students, faculty, and professionals about pollution prevention; create educational materials; provide tools and strategies for addressing relevant environmental problems; and establish a national network of pollution prevention educators.

In addition to developing educational materials and conducting research, the NPPC also offers an internship program, professional education and training, and conferences.

The NPPC provides educational materials through the World Wide Web at this URL: **http://www.umich.edu/~nppcpub/** Please contact us if you have comments about our online resources or suggestions for publicizing our educational materials through the Internet.

Pollution Prevention Concepts and Principles. By Erica Phipps, NPPC Research Assistant.Â Pollution prevention (P2) is the reduction or elimination of wastes and pollutants at their sources. For all the pollution that is avoided in the first place, there is that much less pollution to manage, treat, dispose of, or clean up. P2 can encompass activities such asÂ The National Industrial Competitiveness through Efficiency, Energy, Environment, and Economy (NICE3) project is an-other federal partnership program focusing on P2 and efficient use of resources. The Department of Energy and the EPA provide grants for the development and demonstration of new technologies that prevent pollu-tion through source reduction and energy efficiency. Characterizing Industrial Ecology Industrial Ecology (IE) is currently a broad umbrella of concepts rather than a unified.Â Within this framework, pollution prevention - a well-established industrial-environmental strategy - is presented as the key to IE. Patel (1992) describes IE as a "cradle-to-grave production philosophy, except that in an ideal circumstance there is no grave." Patel's six elements of IE all relate to process and product changes within an individual firm, from just-in-time delivery systems that reduce inventory and waste of hazardous inputs, to engineering controls to assure robust processes.