國立臺北大學自然資源與環境管理研究所

108 學年度第二學期『清潔生產與工業生態』

課程進度(03)：工業生態學簡介－定義、範疇與沿革
Introduction to Industrial Ecology: Definition, Scope, and History

- HISTORY OF INDUSTRIAL ECOLOGY
  - First appeared around early 1970s (Erkman, 1997 & 2001)

    Industrial ecology … began to appear sporadically in the literature of the 1970's. In fact, and not surprisingly, scientific ecologists had for a very long time intuitively regarded the industrial system as a subsystem of the Biosphere. This line of thought has, however, never been actively investigated. … The industrial ecology concept was indisputably in its very early stages of development in the mid-1970's, in the context of the flurry of intellectual activity that marked the early years of the United Nations Environment Program (UNEP).
  - Described by the International Society for Industrial Ecology (http://www.is4ie.org/about)

    A Short History of Industrial Ecology:

    In 1989, Scientific American published what would prove to be a seminal article for the field of industrial ecology. The article by Robert Frosch and Nicholas Gallopoulos was titled "Strategies for Manufacturing" and suggested the need for "an industrial ecosystem" in which "the use of energies and materials is optimized, wastes and pollution are minimized, and there is an economically viable role for every product of a manufacturing process."

    Frosch and Gallopoulos envisioned a more integrated model of industrial activity that would be environmentally sustainable on a global level. Their article was the catalyst for a Symposium held by the US National Academy of Sciences in the early 1990s that has been heralded as a founding event for the modern field of industrial ecology.

    During the decade following the symposium, the US-based effort becoming known as industrial ecology joined with and built upon a substantial body of research, practice and expertise already underway throughout the world, but especially in northern Europe. The field's growth was signaled by two Gordon Research Conferences in the United States as well as a number of special sessions at annual meetings and conferences of various professional and scientific organizations.

    In the late 1990s the field gained increased international recognition through the creation of the Journal of Industrial Ecology -- now a widely respected, scholarly, peer-reviewed journal -- and the establishment of an academic degree-giving program at the Norwegian University of Science and Technology (NTNU).

    ⇨ http://en.wikipedia.org/wiki/History_of_Industrial_Ecology

    ⇨ http://zh.wikipedia.org/zh-tw/工業生態學

- DEFINITION OF INDUSTRIAL ECOLOGY
  - Definition in the Wikipedia (http://en.wikipedia.org/wiki/Industrial_ecology):

    Industrial ecology (IE) is the study of material and energy flows through industrial systems. The global industrial economy can be modeled as a network of industrial processes that extract resources from the Earth and transform those resources into commodities which can be bought and sold to meet the needs of humanity. Industrial ecology seeks to quantify the material flows and document the industrial processes that make modern society function. Industrial ecologists are often concerned with the impacts that industrial activities have on the environment, with use of the planet's supply of natural resources, and with problems of waste disposal. Industrial ecology is a young but growing multidisciplinary field of research which combines aspects of engineering, economics, sociology, toxicology and the natural sciences.

    Industrial ecology has been defined as a "systems-based, multidisciplinary discourse that seeks to understand emergent behaviour of complex integrated human/natural systems." The field

approaches issues of sustainability by examining problems from multiple perspectives, usually involving aspects of sociology, the environment, economy and technology. The name comes from the idea that the analogy of natural systems should be used as an aid in understanding how to design sustainable industrial systems.

- Definition by Graedel and Allenby (2003; 2010): Industrial ecology is the means by which humanity can deliberately and rationally approach and maintain sustainability, given continued economic, economic, cultural, and technological evolution. The concept requires that an industrial ecosystem be viewed not in isolation from its surrounding system, 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 are resources, energy and capital.
- Definition by Lifset and Graedel (2002):

  The very name industrial ecology conveys some of the content of the field. Industrial ecology is industrial in that it focuses on product design and manufacturing processes. It views firms as agents for environmental improvement because they possess the technological expertise that is critical to the successful execution of environmentally informed design of products and processes. Industry, as the portion of society that produces most goods and services, is a focus because it is an important but not exclusive source of environmental damage.

  Industrial ecology is ecological in at least two senses. As argued in the seminal publication by Frosch and Gallopoulos (1989) that did much to coalesce this field, industrial ecology looks to non-human 'natural' ecosystems as models for industrial activity.1 This is what some researchers have dubbed the 'biological analogy' (Wernick and Ausubel 1997; Allenby and Cooper 1994). Many biological ecosystems are especially effective at recycling resources and thus are held out as exemplars for efficient cycling of materials and energy in industry. The most conspicuous example of industrial re-use and recycling is an increasingly famous industrial district in Kalundborg, Denmark (Ehrenfeld and Gertler 1997; Chapter 27). The district contains a cluster of industrial facilities including an oil refinery, a power plant, a pharmaceutical fermentation plant and a wallboard factory. These facilities exchange by-products and what would otherwise be called wastes. The network of exchanges has been dubbed 'industrial symbiosis' as an explicit analogy to the mutually beneficial relationships found in nature and labeled as symbiotic by biologists.

  Second, industrial ecology places human technological activity – industry in the widest sense – in the context of the larger ecosystems that support it, examining the sources of resources used in society and the sinks that may act to absorb or detoxify wastes. This latter sense of 'ecological' links industrial ecology to questions of carrying capacity and ecological resilience, asking whether, how and to what degree technological society is perturbing or undermining the ecosystems that provide critical services to humanity. Put more simply, economic systems are viewed, not in isolation from their surrounding systems, but in concert with them.

  Robert White, the former president of the US National Academy of Engineering, summarized these elements by defining industrial ecology as . . . 'the study of the flows of materials and energy in industrial and consumer activities, of the effects of these flows on the environment, and of the influences of economic, political, regulatory, and social factors on the flow, use, and transformation of resources' (White 1994).
- Definition by Manahan (2001): Industrial ecology is an approach based upon systems engineering and ecological principles that integrates the production and consumption aspects of the design, production, use, and termination (decommissioning) of products and services in a manner that minimizes environmental impact while optimizing utilization of resources, energy, and capital. The practice of industrial ecology represents an environmentally acceptable, sustainable means of providing goods and services. It is closely tied with environmental chemistry, and the two sciences work synergistically with each other.

• SCOPE AND CONTEXT OF INDUSTRIAL ECOLOGY

- Elements Characterizing the Discipline of Industrial Ecology (Lifset and Graedel, 2002)
  - ⇨ The biological analogy

- ⇨ The use of systems perspectives
- ⇨ Role of technological change
- ⇨ Role of companies
- ⇨ Eco-efficiency and dematerialization
- ⇨ Forward-looking research and practice

- Six Principal Elements of Industrial Ecology (Tibbs, 1993)
  - ⇨ **Industrial Ecosystems:** Fostering cooperation among various industries whereby the waste of one production process becomes the feedstock for another.
  - ⇨ **Balancing industrial input and output to the constraints of natural systems:** Identifying ways that industry can safely interface with nature, in terms of location, intensity, and timing, and developing indicators for real-time monitoring.
  - ⇨ **Dematerialization of industrial output:** Striving to decrease materials and energy intensity in industrial production.
  - ⇨ **Improving the efficiency of industrial processes**: Re-designing production processes and patterns for maximum conservation of resources.
  - ⇨ **Development of renewable energy supplies for industrial production**: Creating a world-wide energy system that functions as an integral part of industrial eco-systems.
  - ⇨ **Adoption of new national and international economic development policies:** Integrating economic and environmental accounting in policy options.
- Much of the research focuses on the following areas (Wikipedia):
  - ⇨ material and energy flow studies ("industrial metabolism")
  - ⇨ dematerialization and decarbonization
  - ⇨ technological change and the environment
  - ⇨ life-cycle planning, design and assessment
  - ⇨ design for the environment ("eco-design")
  - ⇨ extended producer responsibility ("product stewardship")
  - ⇨ eco-industrial parks ("industrial symbiosis")
  - ⇨ product-oriented environmental policy

- APPROACHES FOR INDUSTRIAL ECOLOGY
  - Key Questions of Industrial Ecology (Graedel and Allenby, 2010, p.58)
  - Characteristics of Industrial Ecology (Graedel and Allenby, 2010, p.60)
  - Important components in the industrial ecology toolbox (Kapur and Graedel, 2004, pp.3-9)
    - ⇨ Life Cycle Assessment
    - ⇨ Design for Environment
    - ⇨ Industrial Symbiosis
    - ⇨ Ecoefficiency, Dematerialization, and Decarbonization
    - ⇨ Industrial Metabolism
    - ⇨ IPAT Equation
  - Areas classified in terms of *orientation* (Lifset and Graedel, 2002)
    - ⇨ System-oriented: Systemic analysis
    - ⇨ Application-oriented: Eco-Design

- HOMEWORK ASSIGNMENT #2 (Due 2020/03/24):

  請整理、翻譯相關文獻以編寫約 1 頁（A4 Size）之「工業生態學簡史」。

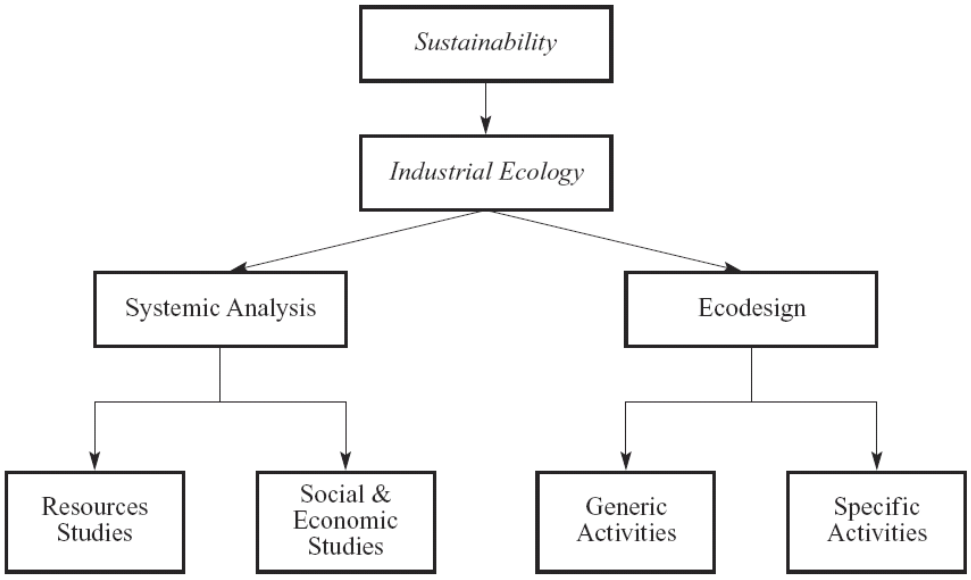

Figure 1.3 Industrial ecology conceptualized in terms of its system-oriented and application-oriented elements

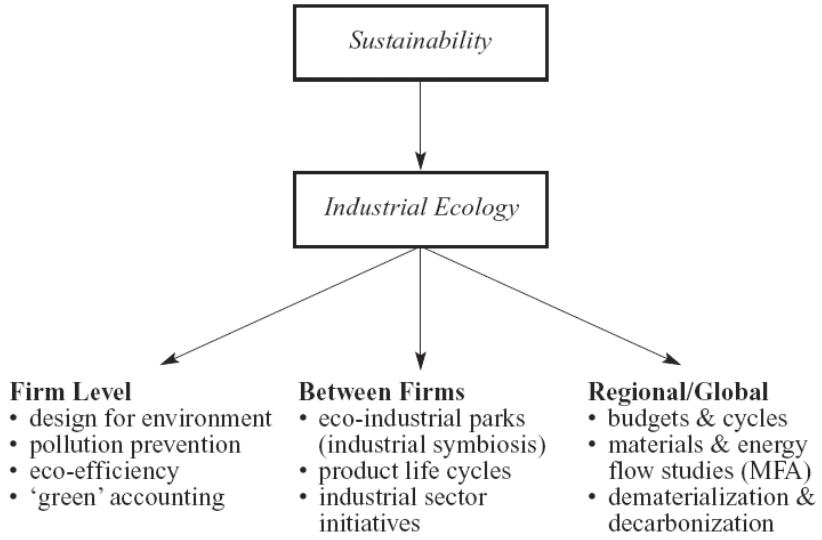

Figure 1.2 The elements of industrial ecology seen as operating at different levels

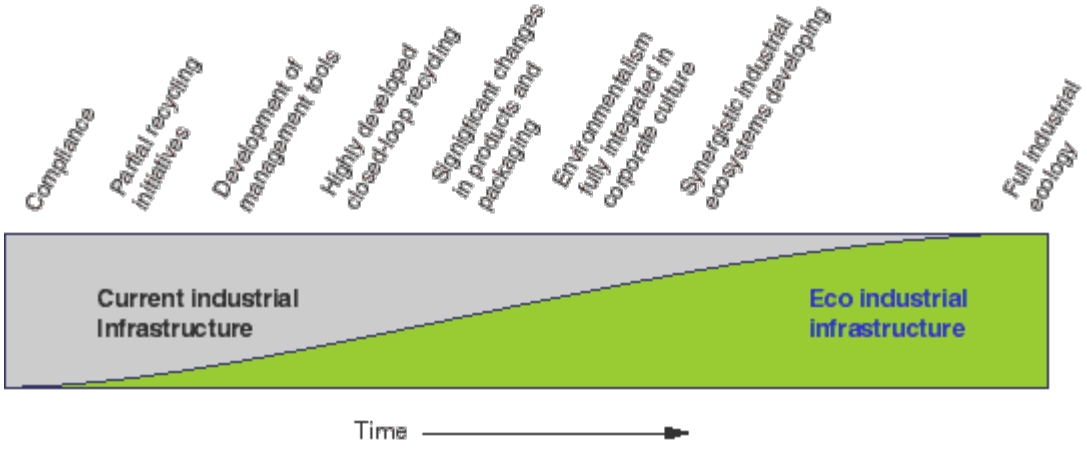

Figure 2: The Emergence of an Eco-Industrial Infrastructure
(http://newcity.ca/Pages/industrial_ecology.html)