國立臺北大學自然資源與環境管理研究所

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課程進度(04)：工業生態學：沿革、範疇與考量面向

Introduction to Industrial Ecology: History, Scope, and Dimensions

- HISTORY OF INDUSTRIAL ECOLOGY
  - History - International Society for Industrial Ecology - ISIE (is4ie.org)

The origins of industrial ecology trace back to at least the late 18th century and to Thomas Malthus' study of the relationship between population growth and economic output. The literature developed in various ways during the next two centuries, notably including the Tragedy of the Commons, Spaceship Earth, The Limits to Growth, and Sustainable Development.

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. At around this time, Graedel and Allenby published their seminal definition of industrial ecology:

> *"Industrial ecology is the means by which humanity can deliberately and rationally approach and maintain sustainability, given continued 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."*

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. The journal is based at the Center for Industrial Ecology at Yale University and is edited in collaboration with the Norwegian University of Science and Technology (NTNU) and Tsinghua University.

In 2003, NTNU offered the first PhD program in Industrial Ecology, followed by a masters program the year after. In 2005, Leiden University and Delft University of Technology started offering a joint MSc degree in Industrial Ecology. Across the globe, industrial ecology is currently taught through individual courses or specializations, often within engineering programs or interdisciplinary degrees that focus on the environment.

In the 2010s, the circular economy became a leading concept in academic, industrial, and policy circles. The circular economy embodies many of the approaches and findings of industrial ecology, including its life cycle perspective, focus on closed-loop systems, design for the environment, and industrial symbiosis. Many circular economy efforts are supported or created by leading industrial ecologists. Moreover, circular economy businesses and other initiatives often employ graduates from industrial ecology programs.

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

⇨ http://zh.wikipedia.org/zh-tw/工業生態學

⇨ Industrial ecology: a new perspective on the future of the industrial system

- 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 modelled as a network of industrial processes that extract resources from the Earth and transform those resources into by-products, products and services 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 behavior 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 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 (2017): Industrial ecology is a comprehensive approach to production, distribution, utilization, and termination of goods and services in a manner that maximizes mutually beneficial utilization of materials and energy among enterprises, thereby minimizing consumption of materials and energy while preventing the production of wastes and pollutants. The practice of industrial ecology involves optimization of materials utilization, starting with raw material and progressing through finished material, to product, and finally to the final fate of obsolete product. In addition to materials and resources, industrial ecology considers energy and capital.

- 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
    - the role of technological change
    - the role of companies
    - dematerialization and eco-efficiency
    - 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.
  - Key Methods and Approaches Introduced by ISIE: Socio-Economic Metabolism, Life Cycle Sustainability Assessment, Environmentally Extended Input Output, Industrial Symbiosis and Eco-industrial Development, Sustainable Urban Systems, Island Industrial Ecology
  - 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
    - eco-efficiency

- 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.3-10)
    - Life Cycle Assessment
    - Design for Environment
    - Industrial Symbiosis
    - Eco-efficiency, Dematerialization, and Decarbonization
    - Industrial Metabolism
    - IPAT Equation

- THE RELEVANCE OF BIOLOGICAL ECOLOGY TO TECHNOLOGY
  - □ The Analogy and a new Definition (G&A, p.41):
    Industrial ecology is the study of technological organisms, their use of resources, their potential environmental impacts, and the ways which their interactions with the natural world could be restructured to enable global sustainability.
  - □ Biological and Industrial Organisms (G&A, p.42)
  - □ Biological and Industrial Ecosystems (G&A, pp.44-47)
  - □ Engineering by Biological and Industrial Organisms (G&A, pp.47-49)
  - □ Evolution (G&A, pp.49-51)
  - □ The Utility of the Ecological Approach (G&A, pp.51-53)

- THE SOCIAL DIMENSIONS OF INDUSTRIAL ECOLOGY
  - □ Cultural Constructs and Temporal Scales: Paradigm Shift (G&A, pp.83-86)
  - □ Social Ecology (G&A, pp.86-87)
  - □ Consumption (G&A, pp.88-89) => utility => value of "goods"
  - □ Government and Governance (G&A, pp.89-91)
  - □ Economics and industrial ecology (G&A, pp.93-97)
    - ⇨ Wealth Wars - Companies More Profitable Than Countries | ABC Finance
    - ⇨ Magnificent 7 profits now exceed almost every country in the world. (cnbc.com)
  - □ Legal and Ethical Concerns in Industrial Ecology (G&A, pp.91-93)
    - ⇨ Equality, Equity, and Justice

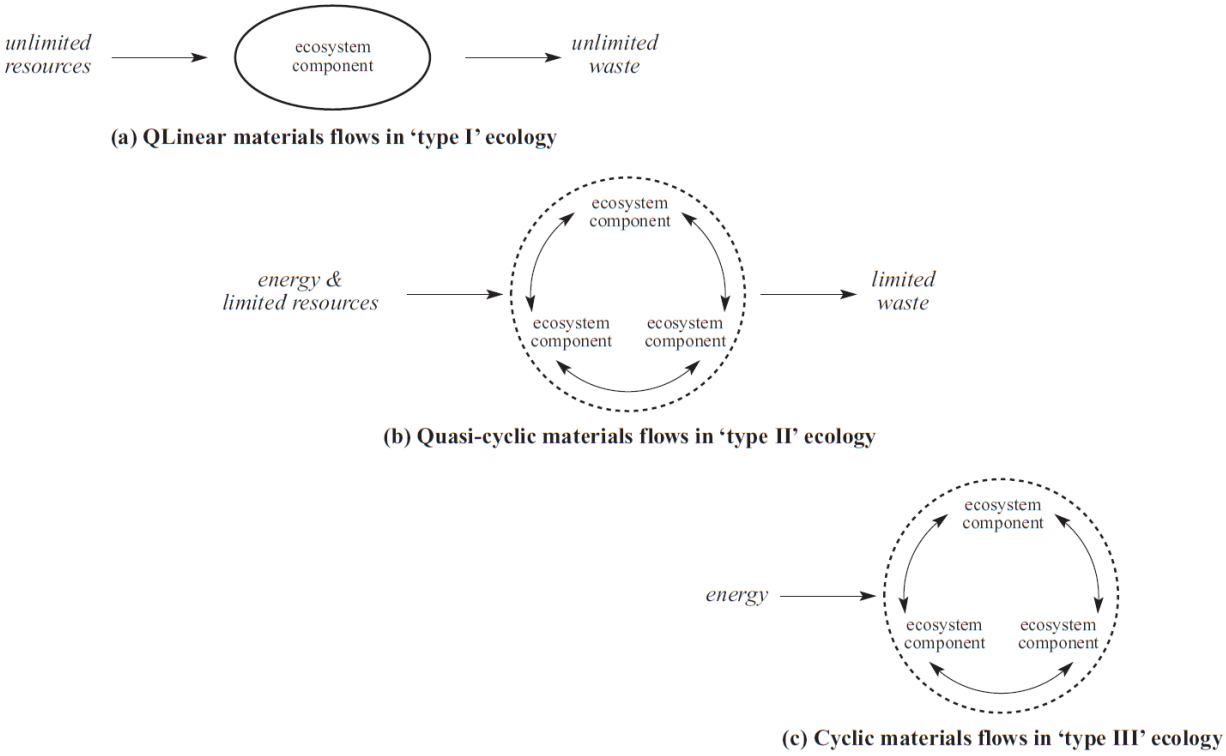

Figure 1.1 Typology of ecosystems

- HOMEWORK ASSIGNMENT #3 (Due 2024/03/19):
  請整理、翻譯相關文獻以編寫約 1~4 頁之「清潔生產與工業生態學簡史」。