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Research on strategies of industrial ecosystem construction

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ABSTRACT

Ecological industry is to realize the harmonious development between economy and environment by planning industrial systems according to material cycle as in the natural ecological system. This paper first discusses the properties of ecological industries, such as industrial ecology is operating and managing traditional industries based on the principles of ecological economics, the core of industrial ecology is the construction and integration of industrial ecosystem. The eco-industry coordinates discrete enterprises and industries and integrates them into optimized industrial ecology chains which establish the "resources - products - renewable resources" of the circular economy mode, industrial ecology helps companies become more competitive by improving their environmental performance and strategic planning; it minimizes energy and materials usage, conserves and restores ecosystem health and maintaining biodiversity. The application of industrial ecology is the practice of eco-industry parks, which are communities of manufacturing and service businesses located together on a common property. The paper further does investigation on strategies for industry ecology system (IES) construction, which include establishing and improving the legal system and industrial policies to promote industrial ecology, collecting more comprehensive information on waste stream from all users, as well as the government should play a key role in coordinating and maintaining the security and stability for the industrial symbiosis network.

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Introduction

Humans over the past 100 years have created more material wealth than the historical summation before. However, this kind of rapid economic growth is based on the "high investment, high consumption, and high emissions" characteristics. It results in resource depletion, pollution, the deterioration of the ecosystem. Industrial civilization pushes the progress of science and technology and material prosperity. At the same time, it also brings a lot of questions. To a certain extent, they have expressed as counter to human and natural. Therefore, human beings have to re-think and re-examine the modernization of production, life style and values, and even seek new ways of development. The applications of circular economy and industrial ecological theory could make the economic development with high-efficiency, Low-pollution of the environment, resources and energy recycling, and sustainable growth.

Ayres R. U., Kneese AV. (1969) brought up the concept of "industrial metabolism" for the first time while studying the flow of materials, based upon which he put forward the epoch-making concept of "industrial ecology". In 1983, six Belgian scholars co-authored and published an important book "The industrial ecology of Belgium", which iterated the Belgian economy with material flow and energy flow instead of the conventional monetary format. In 1989, Frosch A. and Gallopoulos first proposed the concept of Industrial eco-system. They pointed that "traditional industrial activity patterns should be transmitted into to a more complete model: industry ecosystem. In this system, energy and material consumption is optimized, waste discharge is minimized, and the waste of a production process becomes the raw materials of another

production process". They maintain that the way to promote the harmonious development of man and nature is to transform the conventional industrial model into an industrial eco-system, i.e. to enhance the recycling of waste and resource conservation, and to establish a unified model of production. In 1990, United States National Academy of Sciences and the Bell Laboratories jointly organized the first "industrial ecology" Forum. At the Forum, they overviewed industrial ecology concepts, contents, methods, and applications. They also formed the conceptual framework of industrial ecology. The framework describes an industrial bionic system to maintain a sustainable development of the industrial system through imitating ecological systems and structures. In the system, the waste (output) of an industrial activity is the raw materials (inputs) of another industrial activity. The recycle process to reuse the "upstream waste" is realized by the production process of cooperative enterprises within the system. Frosch(1996) believed that an industrial eco-system of industrial metabolism is composed of a series of businesses which are located closely geographically and compensate one another in resources. Allenby (1999) assigned industrial eco-system the very broad definition, "science of sustainability". This classification is persuasive at first glance, but to some extent misleading when following the argumentation of Wilderer(2007b). A more comprehensive discussion of industrial eco-system contribution to ecologic sustainability is presented by Manahan (1999) who proposed that the goal of industrial ecology is to realize sustainability as a means to achieve "the basis for a much more sustainable global industrial system compared to the one that now exists". Basically it is a systematic organization constructed by relationships of industrial co-existence such as enterprises

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share equipments within the system, exchange waste and extra energy etc (Lambert and Boons, 2002).

Through the simulation of natural ecosystems and the establishment of organic circular industrial development model, industrial ecology aims to solve the problems in industrial economic development, environmental protection, and sustainable uses of resources. Similar natural ecological chain within the different industrial enterprises and different types of industries should be set up. Therefore we can make full use of resources, reduce wastes, use recycled materials, eliminate environmental damages, and improve the scale and quality of economic development, achieve sustainable economic development and coordination and harmony between man and the nature. Thus, industrial ecology is a new industrial development approach since the industrialization development, and is also a new industry model to build harmonious development of both the economic society and the nature in a virtuous cycle.

The characteristics of industrial ecosystem

The "industrial character" of industrial ecosystem is reflected in the product design, manufacturing and sales, and the entire usage process, it is a physical and chemical transformation process of natural resources; while the "ecological character" is reflected in the simulation of different natural ecosystems where different biological populations, according to some kind of "symbiotic" relationship, link and live together to form a co-existence and co-evolution process for business cooperation and coordination. Through pollution prevention and internal symbiotic cooperation between enterprises, an industrial ecosystem consists of a number of business enterprise communities to minimize resource consumption and environmental pollution (Daly H.E., 2004).

Generally speaking, an ecosystem has the following properties:

Market-driven initiative

In natural ecosystems, organisms choose their own habitat space and reproduction of life based on the most appropriate survival guidance. In the same way, enterprises of economic system choose the most favorable living environment for development based on the orientation of minimum cost and maximum efficiency. The purpose of businesses is to pursue profit and the most fundamental driving force of business behavior is market-oriented. With more stringent government environmental enforcement, the cost to deal with pollution and waste for an upstream business alone has been rising. If they can cooperate with the downstream businesses who accept the waste as raw material, the upstream companies can save pollution processing costs; and the downstream firms can also be free or have very favorable price to get raw materials. So the upstream and downstream enterprises form a "food chain" under the market guidance, an ecological agglomeration, and eventually the formation of the industrial ecosystem.

Therefore, the emergence and development of an industrial ecosystem is the mimic natural ecosystem's phenomenon of species coexistence and material recycling without external specific interventions. Meanwhile, it is driven by the law of market-value, followed by the process of self-aggregation development from scratch, and achieved in positive externalities through multi-level resources and energy usage during the process of development.

A lot of practice shows that the characteristics of self-evolution of the ecosystem in the industry are prevalent. For example, Kalundborg industrial symbiosis in Denmark went

through a long evolution process. In 1975, their gypsum plant started from the excess use of butane gas refinery by-product. By 1993, their power plants sold processed calcium sulfate to gypsum plant as raw material. By then, Kalundborg industrial ecosystem became mature and all symbiotic cooperation projects are from business considerations for their own interests voluntarily, not from policies and regulations directly imposed by external forces.

The cycle of material flows

The most perfect property of natural ecosystem is characterized by its cyclical factor. Ecological environment and renewable natural resources can be restored and balanced as well as biological species in a harmonious and stable environment survive and multiply. To mimic the natural eco-system, industrial ecosystem adds the feedback mechanism in the traditional linear manufacturing process. In the system, waste can be cycled through the different production process in the multi-level usage of industrial system. So, we can achieve economic efficiency, environment of low-polluting, low energy consumption, ecological harmony and sustainable development, and therefore, to form the ideal state - "the request and give-back to the nature system from human must be balanced".

The cooperation of industrial clusters

Cluster was originally from the ecology. It refers to different ethnic groups who live in the same habitat and these groups form a symbiotic relationship. In the industrial system, different enterprises get together for the existence of a symbiotic relationship and form industrial clusters.

The traditional industrial cluster is only a certain superposition of related businesses within the region, but an industrial ecosystem is composed of a series of producers, consumers, and decomposers in a region to imitate natural systems with resources (including raw materials, products, information, personnel, etc.). as a link to form transference and cooperative relations in industrial clusters, essentially a collection of various partnerships by the eco-industrial chain business model. Therefore, it is essential for an industrial ecosystem to have the mechanism of cooperation between enterprises. Through cooperation, the system will achieve closed loop circle, reduction of material, and multi-level use of energy. Enterprises in the system will improve the viability and profitability, while reduce the negative ecological impacts of industrial activities to save resources and protect environment.

The sustainability of the dynamic adjustment

From an economic point of view, sustainable development is the economic development without reducing the environment quality and destroying natural resources, that is economically sustainable; from the natural point of view, the emphasis is on the coordination between economic development and natural resources under the environmental carrying capacity, this is ecological sustainability. Building an industry ecosystem is a continuous improvement process, not only a gradual adjustment process, but also a dynamic process according to market demand and technical changes to adjust partners and develop new supply and demand relationships. In this process, the linear flow of material (open) system is gradually replaced by cycle (closed) system to achieve the changes of weakening of anti-ecological characteristics and the increasing of industrial ecological characteristics. Ultimately we will build the industrial ecosystem to reduce the natural resources consumption and negative environmental impact, reduce pollution, conserve resources,

protect the ecological environment, and achieve, at the same time, economic and social sustainable development.

Strategies for construction of industrial ecosystem

Ecosystem stability is the system's material and energy supply and demand balance through its own adjustment function when external disturbances cause material and energy supply and demand imbalance to the system. The enterprises within an industrial ecosystem have both economic characteristics of profit-maximizing and ecological characteristics of using the waste as "food". The economic characteristics determine the complexity and difficulty of coordinating the management of enterprise members in the system because of their own business interests and benefits; the ecological characteristics determine the rigidity and uncertainty of the industrial symbiosis system.

Promote green production technologies and clean production of "cell engineering"

Industrial ecology cannot develop without the support of science and technology, the industrial ecology technologies are for environmental technology, or environmentally friendly technologies. From the perspective of industrial ecology, we should promote all the technologies in the "green technology" system such as the technologies which reduce consumption of materials, control the pollution of closed material flow, transfer waste to resources, make things clean, and produce renewable energy (Graedel TE, Allenby B R., 2003). Those technologies will reduce emissions intensity per unit output and change the ecological nature of industrial structure. The enterprise is the micro but main one who carries the implementation of industrial ecology and the cycle-based enterprises are the ecosystem cells. To transfer a traditional system into an ecosystem, we must start from every enterprise's own ecology. We can start from those core enterprises, actively promote clean production of cell engineering, and push the qualified enterprises to establish ISO14001 environmental management system. Through technological innovation and innovation activities, enterprises achieve the goals on "energy conservation, energy consumption reduction, pollution reduction, and efficiency increase," therefore the "win-win" for both economic and ecological benefits.

The path of industrial ecology at Tianjin Development Zone can be described as the combination of "points" and "lines" to realize the overall industrial structure optimization (Li Huiming, 2010). At the "points", an enterprise is treated as a unit, especially those large core enterprises. Through their clean production, fine environmental management, and eco-design and other means, they showed how those enterprises' single technology, product, corporate clean production, and prevention and control can contribute to the Development Zone's ecosystem. Along the "lines", they showed how to improve and promote the industrial symbiosis, the implementation of green supply chain management, the development of the vein industry, optimization of the logistics relations in the park, and the industrial chain optimization.

Construct information sharing platform

The ecosystem node enterprises information sharing, coordination, and cooperation are the base to achieve the goals of efficient use of resources, minimal environmental damage, and waste multi-use. Information platform provides information on industrial park environment performance objectives, environmental management training services, contact services for domestic or international cleaner production centers and environmental agencies at all levels, coordinating by-products

exchange, and collecting data on industrial environmental management strategies and the latest technologies information. The information platform plays an important supporting role in the efficient management and information exchange between enterprises, technical support, and building virtual ecological networks.

Introduce recycling companies and build a virtual ecosystem

In an industrial ecosystem, some enterprises in their production process could not find suitable downstream users within the system for some industrial wastes; or due to technical, cost and other reasons, it is difficult to treat the waste; or within the system the downstream companies cannot absorb the waste completely; then the park must actively introduce a professional waste treatment enterprise to join. The integrated resource recycling company temporarily stores those waste and by-products that cannot be used as in the exchange system and reduce environmentally harmful waste to a minimum level. Recycling companies or so called vein industrial projects are encouraged and supported by government, known as the "Fourth Industry", "Urban Mines." At the same time, using information technology, we can seek new waste of resource utilization outside the system in a larger region, and further build a greater range of virtual ecological network (Virtual-Ecological Networking).

Virtual symbiotic network is a new type of organizational form, which breaks through the traditional fixed geographical boundaries. Using modern information technology, it establishes dynamic alliance with an open flow of information. Based on the needs, it enriches the incoming new businesses to supplement the existing business, increases waste exchange, and enables the establishment of the material flow on the basis of the information exchange.

Select the appropriate governance model for different structure of the system

Ecosystem ecology has different structures due to internal differences in the link form of the industrial ecosystem chain. Based on different structures and different transaction types of the industrial ecosystem, we select a different management model and find the most appropriate organizational structure to achieve stability of the system. For example, for the enterprises in the "many-to-many" ecological industrial chains, they are very flexible and fast adjustment, it is appropriate to adopt market-driven governance model. In the industrial ecosystem, the material exchange must go through a dedicated transport channel and container, this structure is more appropriate to take bilateral governance structure. However, to the repeated exchange for a capital highly specialized business, the solution would be an integrated governance structure. Lubei Chemical Corporation in Shandong China and Guangxi Sugar Corporation are the companies that are highly specialized and pursue economies of scale. Both companies build the ecological industry chain in their branches within the company and all used integrated governance model.

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Tab.1 Analysis of the four governance models

Governance Model	Characteristics	Type of Assets	Exchange Frequency
Market Governance	Many enterprises that meet the requirements ; Standardized transactions; Information transparency ; Market as the major means to adjust changes	No specialized investment	By chance, Repeat
Bilateral Governance	Both exchange parties coordinate and solve their own issues; After the mediation, it is not necessarily in accordance with contract terms, but more with the two sides' negotiated settlement according to the objective results	Medium-specialized investments, including joint mortgage, cross-shareholdings etc.	Repeat
Trilateral Governance	Exists a trusted third party for both parties	Moderate and highly specialized investments	By chance
Integration Governance	One party buyout the other, the transaction continues within the buyer's company	highly specialized investments	Long-term repeated