ANNALS OF THE ORADEA UNIVERSITY
Fascicle of Management and Technological Engineering
ISSUE #1, MAY 2013, http://www.imtuoradea.ro/auo.fmte/

INDUSTRIAL ECOLOGY, A NEW MANUFACTURING PARADIGM

Anca BUTNARIU[1], Silvia AVASILCAI[2]
[1]Technical University of Iasi, abutnariu@tex.tuiasi.ro
[2] Technical University of Iasi, silvia.avasilcai@tuiasi.ro

Abstract**—** Industrial Ecology is a new field of research, which covers the physical, chemical and biological interactions and interrelations both within the industrial systems and between the ecological and industrial systems. The implementation of an IE framework embeds the strategy of clean production and pollution prevention in industrial activities, at corporate level. Such policies must emphasize the activities of waste minimization, recycling, pollution control, reusing, at operational level. The exchange of 'wastes' between independent firms in some sectors has been taking place for over a century, simply because it makes good business sense. The establishment of 'industrial ecosystems', however, is a relatively new phenomenon. The paper presents the theoretical background of industrial symbiosis and practical examples of this new paradigm.

Keywords**—** environmental management, industrial ecology, manufacturing.

I. INTRODUCTION

INDUSTRIAL ecology is an emerging field, which covers the study of physical, chemical, and biological interactions and interrelations both within and between industrial and ecological systems. Implementing an industrial ecology framework incorporates the strategy of cleaner production and pollution prevention in industrial activities. Industrial ecology is concerned with the shifting of industrial process from linear (open loop) systems, in which resource and capital investments move through the system to become waste, to a closed loop system where wastes can become inputs for new processes [1]. Industrial ecology operates at three different levels: the global level, the inter-firm level, and the individual facility level. The inter-firm level is the focus of this work, as this is the interface between the global issues and the practical considerations. Industrial ecology has developed several models and terminologies for inter-firm relationships, including eco-industrial parks, industrial symbiosis, islands of sustainability, industrial recycling networks, and by-product synergies [2]. While these terms are highly interconnected, industrial symbiosis most closely captures the analogy to natural systems inherent to Industrial Ecology, and is a powerful aspect of its framework.

There are numerous definitions in existence. However, some authors have avoided a definitive statement, opting instead to identify key characteristics of industrial ecology and justifying this position by arguing that the term means different things to different people. For the purposes of elucidation, Table I offers a number of definitions by leading Industrial Ecology researchers.

TABLE I
DEFINITIONS OF INDUSTRIAL ECOLOGY

Definition	Reference
[Industrial ecology aims] to develop a more closed industrial ecosystem, one that is more sustainable.	Frosch and Gallopoulos [3]
Industrial ecology … 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 include resources, energy, and capital.	Graedel and Allenby [4]
Industrial ecology takes a systems view of the use and environmental impacts of materials and energy in industrial societies. It employs the ecological analogy in several ways, including analysis of materials flows.	Andrews [5]
… use nature's model of material recycling, energy cascading and solar energy-based sustainable ecosystem in transforming unsustainable, fossil fuel-based and wasteful industrial systems into more ecosystem-like systems	Korhonen *et al*. [6]

II. INDUSTRIAL ECOLOGY – RELATED CONCEPTS

A. The integration of environmental management concepts at firm level

Industrial ecology provides a framework for synthesizing environmental management concepts as cleaner production, pollution prevention, waste minimization, recycling at the corporate and operational level, in order to improve operational efficiencies and reduce the negative impacts of industrial activities on the ecological system. Hamner [7] refers to the relationship among key environmental concepts as a "staircase" of concepts, depicted in fig. 1. These concepts can also be divided into three levels: global/macro-scale, corporate/firm-wide, and operational.

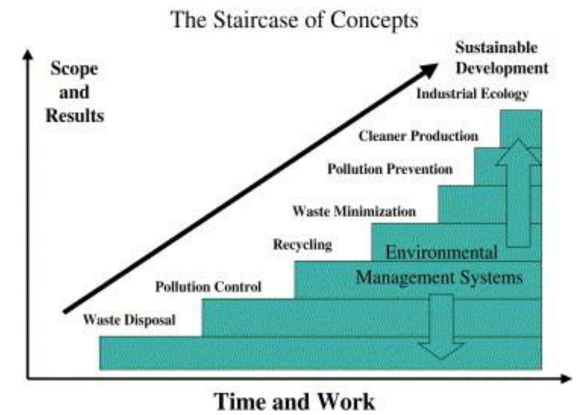

Fig. 1. The staircase of concepts for environmental management systems [7]

B. Industrial ecosystems

'Industrial ecosystems' refer to situations in which a number of different companies, usually in close proximity to each other, exchange a variety 'waste' output. Industrial ecology represents a relatively new and leading edge paradigm for business. It emphasizes the establishment of public policies, technologies and managerial systems which facilitate and promote production in a more co-operative manner. Implementing industrial ecology involves such things as life cycle analysis, closed loop processing, reusing and recycling, design for environment and waste exchange. Technologies and processes that maximize economic and environmental efficiency are referred to as eco-efficiency. The key features of natural and engineered ecosystems are comparatively listed in Table 2.

If we follow the concept of ecosystems, man-made systems such as industrial complexes, a city, or a region, the demand of raw materials (including crude oil) to be abstracted from natural resources could be tremendously reduced. Consequently, the cost of raw material acquisition would decline, and profits would correspondingly rise. To be expected are positive effects on the short and on the long run. The industrial system would approach the state of sustainability. Obviously, application of industrial ecology is a most capable instrument of sustainable development.

Industrial ecology can be applied to man-made systems of very different sizes, complexity, and orientation. Fig. 2 illustrates a man-made system designed according to the principles of natural ecosystems. There is, however, not a uniform guideline that one could follow to design or transform a system into nature-alike one. Each situation needs an individual approach based on the specific framework conditions [8].

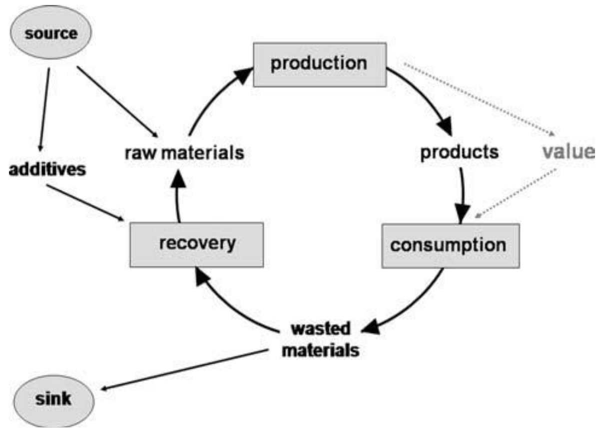

Fig.2. Man-made systems resembling the cycle of materials in natural ecosystems

C. Eco-industrial parks

An eco-industrial park involves a network of firms and organizations, working together to improve their environmental and economic performance.

Some planners and researchers of Eco-industrial Parks have used the team "industrial ecosystem" to describe the type of symbiotic relationships that develop amongst participating firms [9].

An eco-industrial park is a community of manufacturing and service businesses seeking enhanced environmental and economic performance through collaboration in managing environmental and resource issues, including energy, water, and materials. By working together, the community of businesses seeks a collective benefit that is greater than the sum of the individual benefits each company would realize if it optimized its individual performance only. The goal of an Eco-industrial Park is to improve the economic performance of the participating companies while minimizing their environmental impact [10].

D. Industrial symbiosis

The term 'symbiosis' builds on the notion of mutualism in biological communities where at least two otherwise unrelated species exchange materials, energy, or information in a mutually beneficial manner. So, too, industrial symbiosis consists of place-based exchanges among different entities that yield a collective benefit greater than the sum of individual benefits that could be achieved by acting alone. Such collaboration can also increase social capital among the participants. As described in what follows, the symbioses need not occur within the strict boundaries of a park, despite the popular use of the term 'eco-industrial park' to describe organizations engaging in exchanges [11]. At the same time interest began to develop in industrial symbiosis and eco-industrial parks, a number of other parallel tracks advanced that might be construed, broadly, as green development.

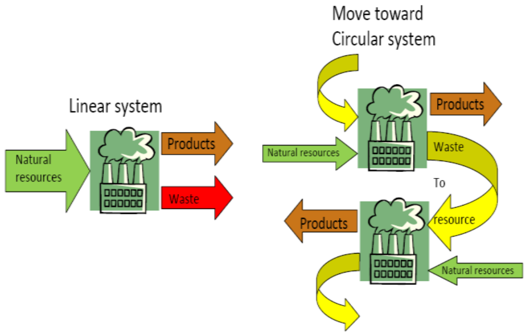

Fig. 3. Industrial symbiosis

These include residential, commercial, industrial, and community development as captured in terms such as sustainable architecture, green buildings, sustainable communities, and smart growth. Eco-industrial development or sustainable industrial development narrows down the possibilities to refer predominantly to industrial and commercial activities and, increasingly, agriculture. Cooperating businesses that include a materials/water/energy exchange or a sharing component qualify the activity as industrial symbiosis [12].

III. INDUSTRIAL ECOLOGY IN PRACTICE

A. Case study

Companies that produce wood waste are spread throughout the Suceava region. These companies produce wood timber. They produce three types of wood waste – sawdust, wooden chips and off cuts from trunk trimming (which can represent up to 36% of the total trunk). There is little to no economic value for these materials yet they can be a major source of environmental problems through polluting water courses and contaminating soil.

The client company is a major wood waste processing company, present in several European countries, producing very large chip boards.

The wood waste in its various forms is collected at the companies and transported to the want company. The waste is then processed to allow its use in the chip board manufacturing process. The company collects and processes wooden waste (sawdust, chops, branches, etc.), into briquettes and sells it as bio-fuel to organizations, institutions (schools, pensions) and individuals in the neighboring area. The processing unit was commissioned with financing from the Romanian Environmental Fund. It is a state-of-the-art installation that automatically conveys, screens, dries, separates pebbles and metallic debris, and does the briquetting of the sawdust.

The wood waste no longer pollutes the environment while also being used in a process that limits the chemicals used in the production process. By using wood waste, 2,558 Hectares of virgin forest have been saved in the Suceava County.

TABLE II
PRESENTATION OF THE KEY FEATURES OF NATURAL ECOSYSTEMS AND THE TRANSLATION OF SUCH FEATURES INTO TECHNICAL TERMS [13]

Key features of natural ecosystems	Key features of engineered ecosystems
Diversity of species	Diversity of companies regarding branch affiliation and size
Cyclic orientation of material and energy flow	Cyclic orientation of material and energy flow
Sector cross-linkage of material and energy flow	Cross-connecting companies belonging to different branches with respect to flow of raw and waste materials as well as flow of virgin and used energy
Establishment of food chains and recovery chains	Recovery of valuable substances from waste materials, and return of these substance into the cycle of materials
Feed-back and feed forward control mechanisms	Feed-back and feed-forward control mechanisms

The importance of the company's activity derives from the fact that it does not necessitate wood as raw material, but only wooden wastes. This becomes a valuable resource by recycling. It is important to mention that in this synergy there is no case of an unprofitable recycling, with the implication of a high added value product being recycled in a lower added value product, inefficiently processed, but a recirculed product that maintains and even raises the initial value of the raw material.

The company will outsource a unit of biomass electricity generation that will use the wooden waste that can not be transformed in wooden placard.

B. The impact on the environment of the wooden waste

In general, wooden wastes are organic materials that do not pollute the environment. The sawdust is used to ameliorate the soil texture. Large amounts of sawdust left on the soil surface modify significantly the quality of the soil. The bacteria that consume carbon in the sawdust also consume nitrogen (essential for the plants' metabolism), leaving less nitrogen for the plants. The impact on water is similar, in the way that bacteria that consume the carbon in the cellulose, also consume the oxygen in the water, conducting to the suffocation of fish and other organisms. The levigate from the timber factories produced by precipitation or the water used by the employees in order to reduce the dust gets easily to natural receptors (rivers, lakes), that pollutes with dissolved materials, as chemicals used to treat the wood. Beside this, the process conveys to the release of toxic lignine in the water (the lignine is a chemical compound, integrant part of the cellular wall of plants, that protect the trees from the predators, but that can levigate in the water and pollute the natural environments)[14].

The raw material used to produce the placard derives from the wastes that today pollute the woods in Suceava county. The processing technology is environmental friendly, using biomass (wooden wastes) as raw material, and, in the near future, as source of renewable energy. Once on the market, the placards are used in the production of furniture and other wooden products. At the end of their life cycle, they become again a source of wooden waste, used to produce a new generation of placard, starting a new economical process.

The solution provided by the synergy has a local application (regional, at a distance of maximum 100 km from the processing center). The wooden wastes from a more distant area are more expensive because of the transport costs.

IV. CONCLUSION

Economically and environmentally desirable symbiotic exchanges are all around us. Identifying and fostering emerging industrial ecosystems offers the promise of many environmental and other benefits. Grounded in what has been learned empirically over the last 15 years about the phenomenon of business co-location known as industrial symbiosis [15], this article helps steer public and private actors to higher probability approaches to resource sharing in geographically related industrial areas by choosing projects with demonstrable kernels of self-organization that can emerge more fully as viable industrial ecosystems.

REFERENCES

[1] A.J.Basu, D. van Zyl, "Industrial ecology framework for achieving cleaner production in the mining and minerals industry", *Journal of Cleaner Production*, 14, 2006, 299-304
[2] N. B. Jacobsen, "Industrial symbiosis in Kalundborg, Denmark: A quantitative assessment of economic and environmental aspects," *Journal of Industrial Ecology*, vol. 10, no. 1-2, pp. 239–255, 2006
[3] D. Frosch, N.Gallopoulos, Strategies for manufacturing, Scientific American, 1989, 261(3)
[4] TE Graedel, BR Allenby, Industrial ecology, New Jersey, Prentice Hall, 2003
[5] C. Andrews, Putting industrial ecology into place: evolving roles for planners. *Journal of the American Planning Association* 65, 364–75, 1999
[6] J. Korhonen, I. Savolainen, M.Ohlstrom., Applications of industrial ecology – an overview of the special issue. *Journal of Cleaner Production* 12,803–7, 2004
[7] B. Hamner, What is the relationship between cleaner production, pollution prevention, waste minimization and ISO 14000? The 1st Asian Conference on cleaner production, Taipei, Taiwan, 1996
[8] M. von Hauff, P. Wilderer, "Industrial ecology: engineered representation of sustainability", *Sustain Sci* (2008) 3:103–115
[9] http://www.indigodev.com/Defining_EIP.html
[10] P. Deutz, D. Gibbs, "Eco-industrial development and economic development: industrial ecology or place promotion?", *Business Strategy and the Environment;* Sep/Oct 2004
[11] M. Chertow, Industrial symbiosis: Literature and taxonomy, *Annual Review of Energy and the Environment;* 2000
[12] P. McManus and D. Gibbs, "Industrial ecosystems? The use of tropes in the literature of industrial ecology and eco-industrial parks", *Progress in Human Geography* 32(4) (2008) pp. 525–540
[13] S. W. Peck, Industrial Ecology: From Theory to Practice *http://newcity.ca/Pages/industrial_ecology.html*
[14] http://www.nisp-ecoreg.ro/studii_de_caz.aspx
[15] M. R. Chertow, "Uncovering" Industrial Symbiosis, *Journal of Industrial Ecology,* no1, 2004