INDUSTRIAL METABOLISM

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Contents

Summary

Environmental consciousness has grown substantially; in the last years the expenditures for cleaning and remediation have reached enormous amounts in the EU. But the goal of environmental soundness of production and lifestyle still seems to be far away and a lot of additional work will be required. Especially in the EU countries, a solution is seen in the transition to a sustainable economy—a new form of economy “which meets the

demands of the present without compromising the future generations to meet their own needs"—introduced to world politics and science by the Brundtland Report. This economy embodies the following principles:

- Energy provision based on solar energy.
- Enhanced use of renewable materials.
- Use of non-renewable materials in industrial cycles.
- Emissions only in the range of natural emission.

Following these rules essential changes in the whole technosphere would be necessary. The most important changes concern the increase in efficiency in energy transformation and in the use of materials.

The vision of industrial ecosystems functioning in harmony with their natural ecosystems is one central aspect in the rich field of industrial ecology (IE). Other facets of IE focus on product and process design (design for environment); recasting of business missions from manufacturing to service of highly durable products (product life extension and the service economy); holistic analysis of materials and energy flows (industrial metabolism and dynamic input-output modeling); environmental information systems, and policy design.

Industrial ecology offers a bridge between the specific innovations occurring in cleaner production and the attainment of an industrial system supplying human needs within the constraints of global and local carrying capacity. IE's concepts and tools will provide the systemic context for design and decision-making regarding such specific changes. With this context we may be able to find the path to sustainable development.

1. Industrial Ecology and Sustainability

1.1Policy- and Material-related Developments

As a result of a national debate on sustainability, many states have established an Environmental Policy Plan—worked out by environmental ministries and focusing on priority issues and core indictors, and targets and measures to reach a sustainable economy. A comprehensive survey on the most relevant activities was summarized by Stefan Bringezu at the ConAccount workshop in Amsterdam (1998). For example, the German Environmental Policy Plan comprises the following targets:

- Energy productivity—increase by a factor 2 (1993–2020);
- Renewable energy—increase to 25 percent until 2030;
- Raw materials productivity—increase by a factor 2, 5;
- Recycling of waste—increase to 40 percent until 2010.

The increase of resource productivity as a political aim has meanwhile caught wide attention under the heading of eco-efficiency. The factor 4–10 target has been adopted by the United National General Assembly Special Session in New York (UNGASS 1997). The UNCSD (1998) has proposed a set of indicators for sustainable production and consumption patterns that comprise material flow, the WBCSD 1998 has taken up the task to guide the increase of eco-efficiency, including resource efficiency. Similar reduction targets target has been adopted e.g. in the Austrian National Policy Plan (NUP 1995), by the Ecocycle Commission of the Swedish Government (1997), and by Finnish interagency activities (Ministry of Trade and Industry 1998).

Given the political background, one may expect the increasing demand for in-depth investigation of material flows in the public economy and at branch level in the future.

2. Basic Concepts of Industrial Ecology

Industrial ecology is a response from the engineering community to the self-destructive impact of the production system on the natural ecosystems on which it depends in many respects. It offers here a systematic approach to change the present unsustainable relationship by looking at and modeling industrial systems in analogy to natural systems. This concerns the relations to the surrounding as well as the internal connections (Commoner, 1994).

Industrial ecology is a general framework for studying and assessing the flows of material and energy in industrial and consumer activities, the effects of theses 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). The principles for successful application of industrial ecology are very close to those of sustainability:

- Industry must function within the constraints of their local ecosystems;
- High-energy and material efficiency guarantee economic benefits;
- Long-term viability has highest priority.

The industrial system is defined as an assemblage of industrial processes, processes that consist of technologies, materials and energy. This system should be treated as “an interacting web of inputs, processes, and wastes, all to be thought of together,” instead of looking at these processes separately.

According to Lowe (1995), industrial ecology gains therefore increasing attention for material management in companies, branches and regions, seeking transformation of the present situation in order to match its inputs and outputs to global and local carrying capacity. The concept of carrying capacity becomes herewith one central, whereas contradictory, point in the most definitions of sustainable development. Rees defines human carrying capacity as the maximum rate of resource consumption and waste discharge that can be sustained indefinitely without impairing productivity of ecosystems.

This shows the necessity to see humans and industrial activity not longer as separated from nature, but moreover in an intense linkage with biosphere. Industrial ecology suggests here the redesign of industrial systems using the model of ecosystems. A central goal is therefore to move from conventional linear systems (extraction–production–consumption–disposal) to a closed loop system of production and consumption.

In our linear system we emphasize material throughput as the basis for valuing activity. In contrast in ecosystems production and consumption are well balanced, the designed industrial systems should closely resemble the cyclic flows in ecosystems. The concept of industrial ecosystems embeds the industrial activity in its local and global ecosystems. In this way the industrial system can move closer to the ecological model in its advantages, but also has to accept its constraints.

2.1 The Biological Analogy

There are two reasons why the term ecology was introduced. Firstly it derives the models for the industrial system from natural ecosystems, sometimes called the "biological analogy" (Wernick and Ausubel 1997). Secondly it views industry in the context of the larger ecosystem that supports it, examining the sources and sinks of the resources in society. Systems ecology has been the primary basis of the biological analogy, focusing on flows of energy, nutrients or pollutants and examines the critical processes determining the efficiency of energy transfer and productivity of the systems.

The components of the system are seen as processors of the flows, biological systems are taken as examples of effective and material and energy efficient systems due to its intense interlinkage. There should also be learnt from biological systems what the boundaries for optimization ought to be to gain appropriate results for the whole system. A distinct deviation from ecosystems must be seen in significant consideration of the welfare of the single actors, which is not of the same importance in ecosystems.

The "biological analogy" is perhaps industrial ecology's most conspicuous feature, and it is by no means the most important. Industrial ecology makes a self-conscious effort to taken a comprehensive, systems view of environmental problems, seeking to avoid the kind of partial analyses that lead to mischaracterization of environmental and social phenomena. This effort to avoid the trap of partial analysis inclines the field toward analyses that are more global in space and time. It also provides pressure for interdisciplinary approaches. Boons and Baas see the features of biological ecosystems that should be mimicked by industrial systems finally as the following:

- Energy requirements should be minimized, as well as waste generation, and the consumption of scarce resources.
- Industrial wastes and discarded products should be used as input in industrial processes "in a way analogous to the cycling of nutrients by various organisms in an ecological food-web".
- The systems should be diverse and resilient in order to absorb and recover from unexpected shocks.

The term "industrial" is derived from its focus on product design and manufacturing processes. So industrial ecology looks at industry as that part of society that produces goods and services, which represents therefore a possible but not exclusive source of environmental damage.

What is new on those concepts, which seem to be based on pure common sense? Indeed nothing is really new as people were centuries ago involuntarily captured by the constraints of nature and learned to live with them. But as science spawned in disciplines to investigate specific problems with more intensity, the view on the whole and the common sense was forgotten.

Whenever problems arise engineers and scientists are blamed for having lost the sense for the whole. So industrial ecology represents to some extent a “back to reason”, but not a journey back to the former situation, more an exercise of applying the principles of living with nature to our developed technical system. In the meantime some examples are exercised, where industrial companies combined to industrial ecosystems, and more projects are on the drawing board. Such concepts demonstrate key steps on the path towards sustainable development.

2.2 Types of Industrial Ecology

Looking at industrial ecology from an organizational sociology perspective different types of industrial ecology were distinguished by Boons and Baas 1997 according to the field of activities of different economic actors:

1. **Product life-cycle:** the boundary of an industrial ecosystem is drawn around the economic actors which are connected with a specific product.
2. **Material life-cycle:** similar to the before mentioned approach, the boundary can also be drawn around actors dealing with a specific material. Another example is the emergence of the steering group “PVC and the Environment” in The Netherlands.
3. **Geographical area:** due to the increasing geographical separation between the production and consumption of the (end) product, drawing the boundary in this way usually excludes the consumption of end-products from the system.
4. **Sectoral membership:** a group of companies performing similar activities can form an industrial ecosystem. The basic organizing principle is the similarity of activities. Therefore it is difficult to imagine situations in which these companies are linked through input–output relations, which are central in the industrial ecology perspective. Instead, sectoral organizations can contribute to industrial ecology by developing overall environmental policy approaches such as the Responsible Care Program of the chemical industry. Also, as in the example of the chemical industry, this sector is so diverse that to a certain extent symbiotic relations do exist between members.
5. **Miscellaneous:** several examples that are given in clarifying the concept of industrial ecology do not seem to be concerned with a specific boundary; instead, they deal with companies that have found a buyer for a (modified) by-product of their production process. These situations have in many cases developed into bilateral relations. More dynamic broker functions like electronic mail bulletin boards of demand and supply of waste materials are developed as well.

Boons and Baas give arguments that the problem of coordination of the activities differs for the different types of industrial ecology. In fact it is an important point, how large the optimization domain should be. In other words where the boundary of the industrial system should be drawn. In examples used to illustrate this perspective, this boundary is sometimes drawn around a geographical region, while in other examples industrial processes related to a certain material (e.g. aluminum) are seen as an ecosystem. Another possibility is that of so-called “chain management.” In this approach, which forms an important part of the Dutch Environmental Policy Program, the chain of activities related to the life-cycle of a product forms the system.

2.3 Limits of the Analogy

An important difference between a biological and an industrial ecosystem is the fact that evolution towards greater efficiency is a spontaneous process in nature, while it needs intentional action in an industrial ecosystem. In other words, achieving industrial ecology requires the management of the relations between the organizations involved. Obviously this management differs for the different types of industrial ecology (Boons and Baas, 1997).

Where reproductive capacity is crucial in biological systems, competitive advantage is the central issue in industrial systems. However, in general, competitive advantage is not related to an efficient use of natural resources. Thus, whilst it is possible for biological ecosystems to develop towards greater (but not the greatest) efficiency without any of the participants or an external actor guiding this development, with respect to their use of natural resources, industrial systems do not evolve in a similar way.

2.4 Shortcomings of Interlinked Systems and Strategies

One basic principle of the analogy is the dependency between organizations, based upon their relations. This dependency arises from the fact that organizations do not control all the resources necessary for its activities. Thus, a producer of milk is dependent on a producer of milk packing. Resource dependency can be of two kinds. First, competitive dependency exists between organizations that have similar goals.

Competitions on the detergents market are a good example. Their dependency lies in the fact that they strive for the same goal: a share of the market. Consequently, whichever share is acquired by firm A; it cannot be obtained by another firm. Secondly, the relation between organizations can be characterized by symbiotic dependency**.** Such a relation exists whenever the output of organization A is the input of organization B.

It is important to note that the dependency between two organizations is not necessarily symmetrical. Indeed, it is possible that a resource is in possession of organization A, while organization A has no comparable resource for organization B under its control.

Three basic strategies to reduce the magnitude of such dependencies can be distinguished:

1. An organization can try to increase the control over a critical resource. In the example of the milk producer, this could be achieved by producing the packaging itself.
2. Increase the control over an actor controlling a critical resource. In our example, this would amount to a takeover of the packaging producer.

3. Decrease the importance of a resource for the organization. The milk producer could achieve this by installing milk-tanks in supermarkets. Consumers could then fill bottles which they bring from home.

3. Industrial Ecology and the Relation to Tools and Methods

Typically, there are two bases for the systems-based work in industrial ecology:

- Life-cycle-oriented analyses (similar to LCA).
- Material-flow-accounting (MFA).

The life cycle oriented analysis can take the form of a formal LCA, but often employs only some parts of the full methodology, helpful to extend the view of a company balance to a life cycle perspective. MFA provides another basis for efforts at comprehensive analysis; an important approach to link these methods was made in the ConAccount networking action, sponsored by the EU. This is why industrial ecology has been described as having a resolute attention to material flows. The effects of kind of attention are “subversive” because industrial ecology “treats with indifference both what is easy to regulate and what is hard to regulate” (Socolow, 1994).

Industrial ecology embraces and builds on many antecedent concepts and tools in the environmental field including design for environment (DfE, also known as Ecodesign), pollution prevention (P2, also known as cleaner production or CP), LCA, dematerialization and decarbonization, extended producer responsibility (EPR), product-oriented environmental policy and cumulative energy analysis. These elements can be organized by thinking of the field as operating at several scales.

At the micro-level, industrial ecology pays attention to the unit processes, facility operations and to firm behavior and organization. At the meso level, it examines industrial symbiosis, municipal or regional material flows and industry sectors. At the macro level, the field focuses on the grand cycles of nutrients (carbon, nitrogen, sulfur and phosphorus), international resource flows; national resource flows, and flows within larger regions such as river basins, Lifset 1998.

Figure 1 depicts the typical boundaries of some tools applied in industrial ecology. LCA and all life-cycle related tools expand the boundaries to the process chain of the product, to consumption and finally down to disposal of possible reutilization, looking mainly at the processes related to the respective product. Whereas SFA follows the flow of single substances or elements (e.g. pesticides or heavy metals) in a region, or in a part of the economy, including mainly those steps which take place in the considered regional boundaries.

Of course the investigation of the situation for a country is also possible. For that all products relevant for the substance and their flows crossing the boundary are investigated, but only the processes within the boundary. For MFA the same scopes can be applied, but typically it is used for balances of public economies or different sectors. In contrast to SFA it looks not at single substances but at the flow of materials, frequently at the total mass flow, distinguished in classes of materials like minerals, renewables, fossils, etc.

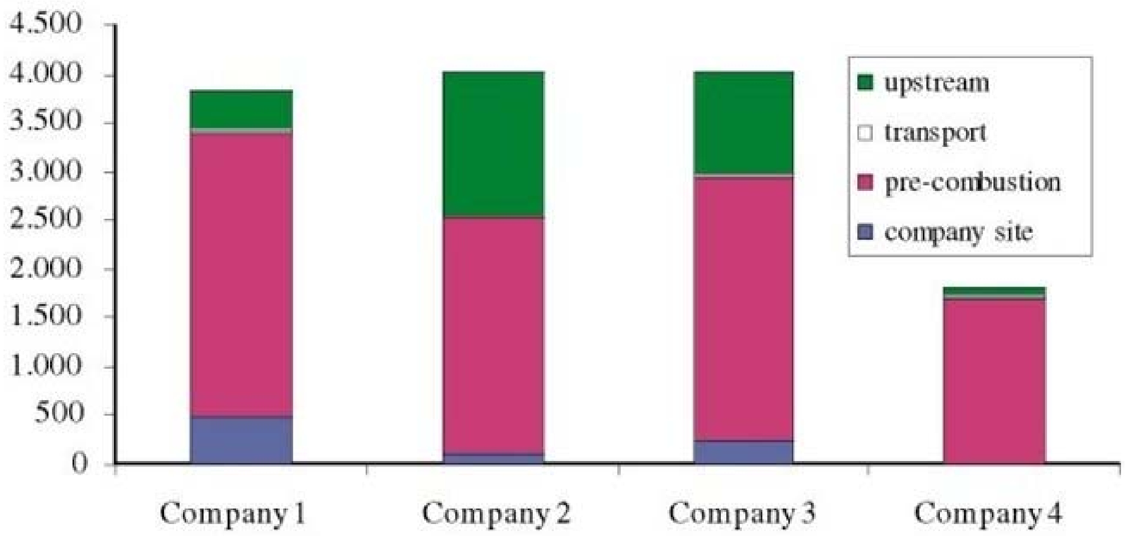

Figure 1. Typical boundaries and relations among the different tools
EMS—Environmental Management System; LCA - Life Cycle Assessment;
SFA—Substance Flow Analysis; CP—Cleaner Production; RA.—Risk assessment;
MFA.—Material flow analysis

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Biographical Sketch

Andreas Windsperger (Univ.Doc. Dr.) is the scientific director of the Institute for Industrial Ecology. After Diploma studies at the University of Technology in Vienna, and at the University of Agriculture in Vienna, he gained a Diploma in Biotechnology and Bioengineering in 1980. After further studies he received his Ph.D. degree in 1995 from the University of Technology, Vienna, with a work on Bioengineering. Since 1990 he has been Associated Professor for Chemical Reaction Engineering at the University of Technology, Vienna. From 1990–1993 he spent almost four years in industry and was responsible for environmental planning and engineering at a chemical factory. From 1994–1998 he was head of the Research Institute for Chemistry and Environment, which since July 1998 has been known as the Institute for Industrial Ecology at the Academy of Lower Austria. Dr Windsperger is a member of various scientific committees and working groups.