DOES INDUSTRIAL ECOLOGY PROVIDE ANY NEW PERSPECTIVES?

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PREFACE

After the early Norsk Hydro initiative in 1993 and two NTVA-seminars on industrial ecology (NTVA 1994, NTVA 1996), the industrial ecology activities at NTNU started off on a more regular basis in 1996. The pilot course “Industrial Ecology and sustainable product design” was a main task, in addition to establish support from and cooperation with Norwegian companies, faculty staff and the administration at NTNU. Brattebø and Røine (1998) and Marstrander et al. (2000) give a thorough description of this development of industrial ecology at NTNU.

In January 1998, industrial ecology was selected as one of the potential focus areas in the Norwegian Research Council financed programme “Productivity 2005” (abbreviated P2005). P2005 aims at “developing competence in the Norwegian manufacturing industry to recognized international standards”. The Preparatory phase, lasting till September 1998, should map the state-of-the art of industrial ecology, both nationally and internationally. The intention was to discuss what does the concept of industrial ecology bring about, how is it understood in academia and in industry, why does industrial ecology represent a fruitful approach to the Norwegian manufacturing industry and what are the most interesting research questions. Brattebø et al. (1999) provides a summary of the activity in this preparatory phase.

This report was written as part of the Preparatory phase, during summer 1998. The intention was to give a conceptual overview to the field of industrial ecology. That said, it is important to emphasise that this is not the one and only answer to what industrial ecology is. The field is emerging and developing and is not (yet) a well-defined area of research and practice. Hence, thorough descriptions and details of the characteristics of industrial ecology were outside the scope of this report.

The reason why this report, written in 1998, now becomes an IndEcol-report is twosided. First, there has been a demand from academia and industry for such and overview, and, secondly, it provides a reasonable overview of the most relevant literature within the field.

SUMMARY

The research question in this report was, as the title alludes: Does industrial ecology provide any new perspectives? If yes, what are the new aspects? To answer these questions, a literature study has been conducted.

The answer to the first question is yes. We claim that what is new about industrial ecology is the expansion of the system borders within which the actors operate. Bearing this in mind, it is proposed that the most important issue in industrial ecology is *to unite the two main interests; ecological sustainability on the macro level and business- economy profit on the micro level.*

This means that knowledge from different actors and disciplines are needed to implement necessary processes of change. This may well be old knowledge that is applied to new issues or new knowledge which is created by blending existing knowledge from various areas. This relates particularly to the understanding of how the interaction among the actors is, as we also attempt to understand the ecological system. As Kiushi (1997) claims, the result of the interaction among the actors gives the system its value, not the value of the individual actors.

CONTENTS

1 INTRODUCTION

During the last ten years concepts such as industrial metabolism, life cycle assessments, environmental management, product-oriented environmental policy, recycling and environmental friendliness have been more frequently used by industry, the world of academia, the media, public administration and NGOs. The amount of such "buzzwords" indicates that there is an increased focus on environmental issues. However, there is a degree of uncertainty about these concepts, both when it comes to what they mean and how they may be positioned to each other. Industrial ecology is a new concept that increases this uncertainty. Which new aspects does industrial ecology include which justify the use of this term rather than any of the other concepts mentioned above?[1] What knowledge do industrial ecologists have which no one else has? This working paper describes some of the new elements and the perspectives which industrial ecology brings to activities focusing on environmental challenges[2].

Industrial ecology is spoken of as a concept, a paradigm, a strategy, a tool and a method, depending on the actor or the professional field one is based in, and the motives the actors have[3]. A person in the process industry may, for example, consider industrial ecology as a shift from traditional process oriented HES activities to a system and lifecycle-oriented product focus (Marstrander 1994). This may reduce the consumption of materials and energy, which in turn will reduce financial costs for companies while also benefiting the environment. A person in an environmental protection organization may, on the other hand, consider industrial ecology more as a macro oriented concept reducing the overall consumption in order to promote sustainability.

Industrial ecology raises so many basic and complex issues that several actors *are* needed to handle this challenge, as "everybody cannot be engaged in everything". The aim of this working paper is to find the common

[1] The term *new* may have many interpretations, all depending on what it is related to. In a time perspective which starts with the iron age, the car is a new invention, but the if we start from the industrial revolution it is an old invention. Another point is what can be called new with respect to content. The existence of atoms was proven in the 1600s, but atoms as such were not new. The discovery of atoms thus only meant that the human explanation mechanisms and perception and knowledge about nature and how it functions were expanded. A third question is how new something must be in order to be considered new. It is also important to be able to discuss what is potentially new within industrial ecology, but so far not yet realized.

[2] What the environmental challenge is depends on geographical location, industry, actor and so on.

[3] The actors here may roughly be classified as industry, academia, administration/public authorities, NGOs, media and consumers.

denominators that justify different approaches utilizing and interpreting the industrial ecology concept in the same way. This makes it necessary to find common denominators for the various actors. One obvious common denominator is *change*, but the question is changes in relation to what and towards what?

2 A BRIEF LOOK AT THE CONCEPT OF INDUSTRIAL ECOLOGY

Industrial ecology is not a separate, established science, but rather a young and immature concept that has not developed its own "personality" yet. In this sense it is necessary to distinguish between 1) the (theoretical) potential of industrial ecology and 2) the actual implemented practice of industrial ecology as it is now. Thus it is yet difficult to state something *absolute* about what is and what is not industrial ecology. In the so-called absolute sciences, which some claim that natural science is an example of, it is asserted that truth is something which is discovered/found, in contrast to those who argue that truth is something that is created (Rorty 1989). The latter believes that truth is socially constructed, being created by how we perceive and explain the world. The truth is created through our language and perception/interpretation of terms and concepts. Industrial ecology can be said to feature such a view on science. An understanding that knowledge and identity are socially constructed is an important element in a sustainable paradigm (Ehrenfeld 1995:11). It must be up to the various actors to create this science, requiring humble and respect for each other and the interests of others.

Industrial ecology is about sustainability, and has developed from the concept of sustainable development (Ehrenfeld, 1995). The idea of sustainable development[4] has come about because of our feelings of anxiety when it comes to the future of mankind on Earth, and this planet's ability to cope with the consequence of human activities. These consequences may, for example, be emissions to the soil, water and air (the earth's capacity to cope with waste) and consumption of both renewable and non-renewable resources (the earth's capacity to supply its population with the necessary resources)[5]. Both sustainable development and industrial ecology are founded on the idea that *the earth is a closed system with limited resources and restricted waste capacity*, a fact which human actions and activities so far appear to have taken little heed of (Ehrenfeld 1995).

Behind this concept we find i) the inseparable relationship between man and nature, and ii) nature as the model for organizing our society. Industrial ecology may be considered a set of ideas (theoretically/conceptually) and methods (practically/instrumentally) which use the natural ecosystem as their metaphor and model to express how the industrial society should be organized and function. The natural ecosystems are the most perfect systems we know;

[4] See Ehrenfeld (2000) for a discussion on the differences between sustainability and sustainable development.

[5] See for example Ayres and Ayres (1996) for a discussion on different resources and industrial metabolism.

with no waste, with self regulation (feedback mechanisms) and closed material loops, i.e. sustainable systems. Industrial ecology is postulated as one possible way to approach the objective of sustainability.

The challenge is thus to develop methods, models and tools based on ecological principles and in accordance with the carrying capacity of nature. The central issue is therefore *implementation of the desired change*, where industry, academia, administration, media and the market are all actors able to influence the necessary processes of change. The problem is to pinpoint what the desired change is, as there are many actors with different needs/interests, not all necessarily wanting to go in the same direction and with the same pace.

In practice, industrial ecology has emerged during the last ten years, where especially industry has been a catalyst for its acceptance. Quite a number of articles have been written, starting with Frosch and Gallopoulos' article "Strategies for manufacturing" in 1989, all deserving of the category "industrial ecology", but there is still no complete agreement as to what industrial ecology really should deal with (Erkman 1997, O'Rourke et. al 1997). In 1997 the first issue of the periodical *Journal of Industrial Ecology* appeared, published by MIT Press in the USA. The ideas expressed here are that "...industrial ecology systematically examines local, regional and global uses and flows of materials and energy in products, processes, industrial sectors and economies. It focuses on the potential role of industry in reducing environmental burdens throughout the product life cycle..."[6]. This description is closely connected to industrial metabolism (the study of stocks and flows of materials and energy) and the roles of different actors to implement necessary changes. It speaks of the aims of industrial ecology as "reducing the environmental burdens throughout the product life cycle". This description is only in a limited way related to sustainability, being *too* micro-oriented, as it takes products as given and opens for "business as usual"-optimization, which is not consistent with designating industrial ecology as a new paradigm (Ehrenfeld 1995). Below we shall outline what may be the central issue of industrial ecology.

[6] Key words for the periodical include i) industrial metabolism, ii) dematerialization and decarbonization, iii) lifecycle planning, design and assessment, iv) environmentally correct design, v) extended producer responsibility, vi) industrial ecoparks, vii) product-oriented environmental policy and viii) eco-efficiency.

3 THE CENTRAL ISSUE OF INDUSTRIAL ECOLOGY

3.1 Five elements of industrial ecology

As up to now no strong common understanding of industrial ecology exists, it may be a useful point of departure for describing the new ideas of industrial ecology to establish agreement on what in fact is the central issue of industrial ecology. One of the publications most often referred to defines industrial ecology as follows:

"Industrial ecology is the means by which humanity can deliberately and rationally approach and maintain a desirable carrying capacity, given continued economic, cultural and technological evolution. The concept requires that an industrial system be viewed not in isolation from its surrounding systems, 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 include resources, energy, and capital." (Graedel and Allenby, 1995, p. 9)

Based on this, some special characteristics of the concept can be established:

1. The systems approach
2. The lifecycle perspective
3. The interdisciplinary approach
4. Optimization of capital, resources and energy
5. The interaction between man and nature

The three first elements are actually measures or tools to help attain the aims of industrial ecology, thus not providing any answer as to what industrial ecology actually is or what is new about it. Systems approaches, lifecycle perspectives and interdisciplinary approaches must be related to something. This "something" is what constitutes the central element of the issue. When it comes to the systems approach, this is, however, also a premise behind industrial ecology in that an ecological approach explicitly *implies* a systems approach. The fourth item is difficult as it is hard to optimize a number of parameters at the same time, and because it does not emerge clearly what the object should be optimized in relation to (capital, resources and energy are vague concepts). Furthermore, optimization has been the aim for quite some time now, thus this does not imply anything new. What is new, however, may be that we are now endeavoring to optimize larger systems, in contrast to previous sub-optimization practice.

The fifth item above is important. The relationship of interests between man and nature, between industrial and natural metabolism, has been discussed for a number of decades, including in "The Tragedy of the Commons" (Hardin 1968), the Gaia theory (Lovelock 1979) and "The Limits to Growth" (Meadows et al. 1972). These describe the inconsistency which exists between human activities and nature's tolerance limits. Industrial ecology is founded on these ideas. Ehrenfeld (1995) describes the problem which industrial ecology reveals as: "the scale and the pace of development are inconsistent with the carrying capacity of the earth.", and we thus "have to rethink and reconstruct the fundamental relationship between man and nature". Both these issues require attention on the macro level.

3.2 The industrial ecology system

Implementation of the desired change related to sustainability makes the micro and macro levels an important concept within industrial ecology. In the words of Sagar and Frosch (1997), "...it is necessary to analyze the system at a larger scale to grasp the context, and at a smaller scale to understand the underlying mechanisms". The micro level is the level where mechanisms and details are studied, where individual actors operate and are parts of a larger, defined system. The micro level is characterized by a bottom-up approach. An example of this is microeconomics which "...is the part of social-economics which deals with the problems of each individual or within the individual company..." (Gyldendal 1994).

On the macro level we consider the totality and long lines of a defined system and the interaction between actors in this system, as well as the total impact and consequences of this interaction. Macro levels are characterized by an aggregated top-down approach. An example of this is macroeconomics (socio-economics) which "...deals with the total figures of social-economics,... and attempts to provide a total overview of social-economics in contrast to microeconomic theory." (Gyldendal 1994).

What is it that characterizes micro-levels and macro-levels and their interaction in the context of industrial ecology? This depends on the system that is defined. All the actors to agree on a common issue must define the same system. The aim of the systems delimitation must be to define the system in such a way that the ecological interests on which industrial ecology is founded, are considered. This is shown in Figure 1 below.

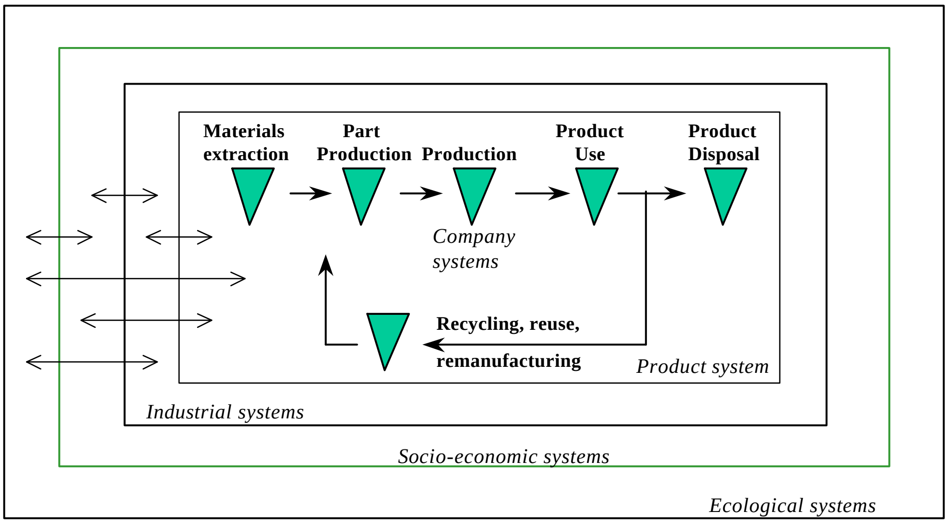

Figure 1: The industrial ecology system

The figure shows the different components in an industrial ecology system, and how they relate to each other. *The ecological system* (the Earth's resources) is decisive and determines all human activities on Earth, constituting the boundary conditions that human activities must relate to. The socio-economic system, which is then a subsystem of the ecological system, consists of social, political, cultural and economical institutions. These are boundary conditions for the *industrial systems, product systems and company systems.* Examples of socio-economic institutions include legislation, regulations, taxes and fees. The industrial systems consist of all industrial activities, including infrastructure and interaction within the systems.

Furthermore, the demand from society and industry is decisive for the *product systems*. A product system consists of a product itself and all the factors that are needed to make the product function as intended. Within the triangles in the middle of the figure, we have *the individual company* that actually manufactures these products. Even though it is not quite correct nor simple to give a rigid definition of what is the macro level and what is the micro level in the figure above, we may roughly state that the two outer rectangles, ecological and socio-economic systems, belong on the macro level while the three inner rectangles belong to the micro level.

Some of the criticism leveled at industrial ecology (and sustainable development) refers to the fact that it is so comprehensive that it may indeed include everything. However, it is necessary to acknowledge that the issue raised by industrial ecology *is* complicated and difficult. If it were not, we would not be facing current environmental challenges, nor would there have been a need for a paradigm shift which Ehrenfeld (1995) argues for. However, it is always necessary to weight between, on the one hand, simplifying a system so that it will be operative and manageable and, on the other hand, rendering and handling a picture of reality that is as realistic as possible. Industrial ecology, seeks, as we shall see later, to be operative, practically oriented and focused on implementation where industry is a very important actor. It is emphasized, for example by the Brundtland Commission, that elements which include improved assets, reduced poverty, democratic development and human rights are important for the development toward a sustainable society. Even if there is an obvious link between these elements and industrial ecology, this is not considered to be within the core area of industrial ecology. In that sense we shall always operate with sub-optimizations.

However, at least one important element is missing from this description – the interaction between the levels and the dynamics of this. Capra (1996) and Kuishi (1997) consider this to be a vital part of any living system. The interaction between the levels and the actors, shown by the arrows in the figure, ensures that not only the societal and industrial boundary conditions are decisive for the existence of individual products. There is also influence from within when companies, for example through advertising, *create* needs in society. As mentioned above, however, the ecological boundary conditions are absolute (the earth is a closed system), and the stability of the system will be threatened if the levels within grow so large that they press from within.

Industrial ecology may thus be seen as a way of thinking to carry out and to obtain change in a direction towards sustainability

3.3 Interests on micro and macro level

This discussion shows that industrial ecology assumes both a macro and a micro perspective. Industrial ecology has a macro perspective because its main aim is sustainability. It has a micro perspective because what happens on the company, product and industrial levels are decisive for society and ecology through interaction. The challenge will thus be to determine how the various levels may influence each other so that sustainability is attained. Which consequences will activities on the micro level have for the macro level and vice versa? If we look from the micro level it is interesting to discover how actors on this level, for example industry, can influence and minimize the consequences of their own activities on the macro level, while from the macro level, we can ask ourselves how societal framing conditions can be designed to enable sustainable operations within industry.

A specific example of different interests on the micro and macro levels is the relationship between ecological sustainability (macro) and business-economy profit (micro). Industrial ecology builds on the idea that the Earth is a closed system with i) limited resources and ii) limited waste handling capacity. As to the first point, the market mechanism (on the macro level) ideally regulates the scarcity of resources by increasing the price of this resource. This applies to resources that may be used directly as raw materials, for example aluminum and oil. A future scarcity is also included in this price. On this point the market mechanism works well. As to the other point, the market mechanism does not function that well. The impacts of human activities, for example pollution, degradation of biological diversity and depletion of resources resulting from the consumption of other resources (forests dying out because of acid rain caused by the burning of coal for power), have not to a satisfactory extent been included in the market mechanism. These impacts are externalities that per se mean that they are external to the market and the calculation. By putting a price on these impacts, internalizing the externalities, we arrive at a more correct price for a product. The price will, ideally, reflect the damage that the product causes to the environment during its entire lifecycle. Lack of information, of feedback and of knowledge of future costs make, however, this price setting a problematic task.

Several researchers go even further, claiming that for sustainable development, attaining correct prices is not sufficient. It is just as important that prices are correct *in relation to* the Earth's limited resource base, in other words that the level/volume of the activities is correct. Georgescu-Rougen (1971), Daly (1991), O'Neill (1996) and Ehrenfeld (1995,1997a, 1997b) especially support this view. They claim that the economic system is a subsystem of the natural ecosystem, and that the volume (throughput) of the economic system must not grow to such a size that it threatens the stability of the ecological system. This means that even if prices are correct we do not necessarily achieve sustainability. This is also based on the second law of thermodynamics with respect to entropy in a closed system.

These arguments are based on a broad systems definition of industrial ecology. It is important to point this out as O'Rourke et al. (1997) in a critical commentary observe that "by drawing the industrial box small enough, anything it seems can be an optimized ecosystem". This leads us to the second "main interest" which industrial ecology must address, i.e. business-economy profits. Criticism of industrial ecology (O'Rourke et al. 1997) claims that it has developed into an incremental change strategy where individual products are in focus, and that it has not developed according to the intentions and aims of sustainability. There is too little focus on the improvement potential in large systems on the macro level, such as infrastructure (transport, energy, buildings, recycling), and on the consumer level, both elements of great importance for the total burden on the environment. The reason may be that various actors place different meanings and interpretations into the concept "industrial ecology", that the development of industrial ecology so far has been dominated by industry, and that the *potential* of industrial ecology so far has not been "triggered".

Industry sees industrial ecology as a strategy for achieving a possible competitive advantage, both in the short and the long term, as it is expected that the market will show greater environmental interest in the future (Hagen et al. 1998). "Greater environmental interest" in this context means that the consumer buys products which are the most environmentally friendly alternative seen from a lifecycle perspective, and that they are willing to pay more for them. The interests of the market are also the interests of business, and industry's motivation is to position itself in a future market. This has led to a transition from an authority-driven to a market-driven environmental policy. That this creates win-win situations, where activities are profitable both for the company and the environment is, needless to say, no disadvantage. As stated above this touches on the core of industrial ecology as business and industry consider improvements in the environmental performance of a product as improvements to the environment. This is not necessarily the case as, for example, environmental improvements will not occur if the consumption of a product increases more than the environmental gain per produced unit or if a new product is marketed in addition to existing products. The great paradox here is that even though the last ten years have shown an increased environmental focus, increased systems approaches and increased interest on the part of industry, the most important indicators of the state of the environment show that the situation is deteriorating (EEA 2000). This points out how inadequate it is to focus only on a micro level. Industrial ecology is more than an industrial strategy to attain increased competitive power.

Here we have described two main interests which are at the core of industrial ecology; ecological sustainability on the macro level and business-economy profit on the micro level. *The most important issue may be to unite these two interests.*

Many argue that the concept of eco-efficiency is very important in industrial ecology. Eco-efficiency has been defined by the World Business Council for Sustainable Development (WBCSD) as:

> "Eco-efficiency is reached by delivery of competitively priced goods and services that satisfy human needs and bring quality of life, while progressively reducing ecological impacts and resource intensity throughout the life cycle, to a level at least in line with the earth's estimated carrying capacity" (BCSD 1993)

Lehni (1998) explains this simply by "doing more with less".

This may also be formulated as:

$$\text{Eco-efficiency} = \text{Product value/ environmental influence}$$

This definition applies to the micro level. It considers improvements for each individual product or for each individual company, but does not include the impact resulting from the volume at which the product is manufactured, nor does it relate this to the total burden on the environment. This means that improving the environmental performance of each product, increased eco-efficiency, only represents a suboptimization of the system as an entity.

If we may consider nature as one of a number of actors in the industrial system, the degree to which each product represents an environmental burden is in itself uninteresting. Nature has to cope with the *total environmental burden*. The total burden on the environment depends on volume and environmental burden/volume. It is thus important to determine how these two parameters may be reduced, and how this can be made compatible with i) productivity and ii) industry's aim to maximize profits.

The new aspect of industrial ecology may thus be claimed to be that it relates individual companies' "improvements" not only to products and processes, but also to the total burden on the environment which nature can tolerate. Hagen et al. (1998) have referred to a case showing the difficulties implied in this, where 74 % of the companies respond that they consider their operations sustainable, while 69 % believe that the environmental situation eventually will threaten the basis of our existence. Industrial ecology is an attempt to be the link between micro and macro interests. The challenge of industrial ecology is to unite these two interests.

A consequence of this is that the individual firm should not judge their own environmental performance in isolation from other companies, sectors and value chains. Industrial ecology, accordingly, motivates collaboration and network initiatives to improve the eco-efficiency of the larger system that the individual firm is a part of. Examples here are integrated chain management, producer responsibility and industrial eco-parks.

4 IMPORTANT ELEMENTS OF INDUSTRIAL ECOLOGY

In this chapter we shall examine decisive factors or important measures to counter the important problems industrial ecology tries to address.

1. Systems and lifecycle approach
2. Ecology
3. Economy
4. Technology
5. Actors
6. Interdisciplinary approaches
7. Implementation

4.1 Systems and lifecycle approach

A systems approach is a measure for examining the issues raised by industrial ecology. So what does a systems approach mean? First, it means analyzing the entire defined system as an entity, including results and consequences. A good example of a systems approach is to consider a football team. The better team "on paper" is not necessarily the winning team. The team consists of individual players, and all experience indicates that the result the team achieves, is not the sum of individual achievements by the players. It is rather a result of how they *interact* as a team. This interaction is also seen in nature. It is not the value of each individual that creates the total value in an ecosystem, rather it is the interaction going on in nature which creates the value (Kushi 1997). In an industrial ecology perspective, it is thus necessary to improve the meshing of various actors to attain an optimum result. The underpinning for this is that there is agreement on what the aim of the interaction is.

Second, a systems approach means that the needs and interests of the actors in the system must be considered. The transition from end-of-pipe solutions to preventive approaches is an example of this. In this way we avoid focusing on (problem) symptoms, rather focusing on the problem core, the cause, and its driving forces. Third, models and tools are needed. A systems approach might thus be a promising model that may explain, describe and predict actual changes and events in complex systems.

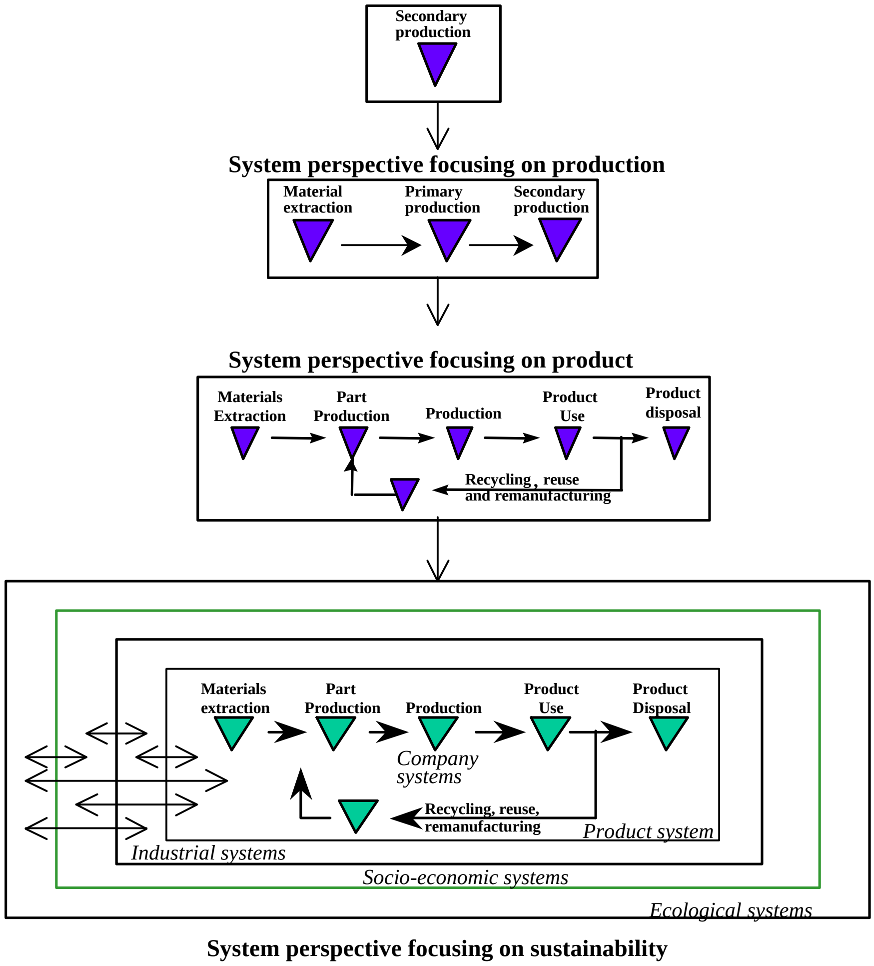

Figure 2: Different focuses of systems approach

As shown in Figure 2, a system perspective is by no means an unambiguous concept, as it may include a focus on production, on the product and on sustainability. A process engineer may strive to close material and energy loops in his facility (production). However, this is nothing new. A product designer may strive to close material and energy loops for the product throughout its entire lifecycle, from the extraction of raw materials to production, via transport and consumption to recycling, reuse or being placed in a landfill. This implies some innovation as it is recognized that the product has caused an environmental burden throughout its lifecycle. If the systems perspective focuses on sustainability, shown at the bottom of Figure 2 which is identical to Figure 1, the operation must also be related to production throughput, energy sources, resource consumption and so on. O'Rourke et al. (1997) claims that the current inconsistency between aims and strategies in industrial ecology is the uncertainty as to whether the systems perspective should be focused on products or sustainability.

Within the defined systems there are flows of material and energy, in addition to flows of capital and information. A core element of industrial ecology is to understand these flows and the environmental impacts they may cause. (Ayres 1989, Ayres 1999). Knowledge on material and energy flows, in particular, is the basis for carrying out changes in a defined system. Several forces decide these flows; natural forces, structural forces and forces made by the actors. The natural forces are the chemical, biological and physical forces on Earth, both on macro (gravitation) and micro (chemical bonds) level. The ecological systems are driven by these forces. The structural forces are the conserved forces appearing in infrastructure, political system, economic system and the culture. The forces are a result of the actions done by the different actors in the society. These actions ensure the dynamics in society.

4.2 Ecology

Ecological background is another main idea in industrial ecology. Mechanisms and functions in natural ecosystems are used as a metaphor for what we should study and how to understand industrial systems as part of our society. We particularly endeavor to copy mechanisms and functions of natural systems, especially those linked to the nutrition chain, the use of renewable energy and the transformation of waste into new production.

Industrial ecology has two analogies to natural ecosystems: i) The interaction between man and nature and ii) The natural ecosystems as the model for organizing the industrial society. Keywords in this respect are feedback mechanisms, dynamics, interaction and holism. Ehrenfeld (1997b) mentions three central concepts in industrial ecology that are all strongly tied to conditions in natural ecosystems: i) connectedness, ii) community and iii) cooperation. These concepts are in many cases contrasts to the conditions we see in industrial societies where reductionist knowledge and administrative systems (in contrasts to connectedness), competition (in contrast to cooperation) and individual autonomy (in contrast to community) dominate. This emphasizes the importance of both a system perspective and of an interdisciplinary approach in industrial ecology, but also of the need to change current practice and implement more ecologically based models and methods.

4.3 Economics

Economics is the central premise in industry. The requirements for profits and competitive power generally direct company choices. It is not possible to implement solutions in industry that directly conflict with financial considerations. At the same time it should be possible to turn company priorities in the direction of placing more weight on long-term competitive power, where the environment is included as a competitive factor. We see this in many cases already. It has moreover been documented that a number of environmental investments concerning cleaner production also are financially profitable in the short term (the win-win situation) (Amundsen 1992, Brattebø 1995, Hagen et al. 1998). The dilemma linked to economy as a premise is that social-economic and environmentally advantageous solutions frequently are not realized because they are not sufficiently interesting when it comes to business-economy interests. Industrial ecology must take this dilemma seriously, as we are striving to find solutions that can have a beneficial impact on the societal level.

As mentioned above, Daly (1991), among others, claims that the economic system is a subsystem of the natural ecosystems, and that the volume (throughput) of the economic system must not grow to such a size that it will threaten the stability of the ecological system. This represents a contrast to the current globalization of trade and capital flow, which a growing number of researchers are beginning doubt, is sustainable.

4.4 Technology

For industry, technology and technological change are obviously a central premises for their activities and for improving their competitiveness. Technological change may, however, emerge on different levels. On a company level, incremental product or process innovation is the major occurring change. Technological knowledge on a high level is a prerequisite for this. Particularly when there are improvements of existing processes and products, the changes are incremental. It seems, however, that more radical changes are possible when entire new development projects are at task. On a society level, changes in infrastructure and critical technologies (technologies that are deciding for other smaller products, i.e. the energy system (electricity or water-based) decides the products within houses for heating (panel oven or radiator)) occur as a consequence of long-term planning and huge investments. The diffusion of technologies can be explained as S-curves (Grübler 1998). To understand the dynamics of technological innovation and development, including S-curves and technological trajectories, technological knowledge must be seen in the context of other natural-science and social-science and cultural-science knowledge. This is important because technological changes and improvements take place both on production level, product level (micro) and system level, and all are needed in an industrial ecology perspective. Figure 3 below shows that the incremental changes and redesign of products do not have the greatest potential to contribute to significant environmental improvement, while functional and system innovation have the potential to do so. Any improvement or innovation has a negative environmental impact in the initial phase. Design, development and production of new products require additional inputs of resources and imply extra emissions. The more fundamental changes, the more negative environmental impact will be in the initial phase, due to high infrastructure investments and rebuilding of existing infrastructure.

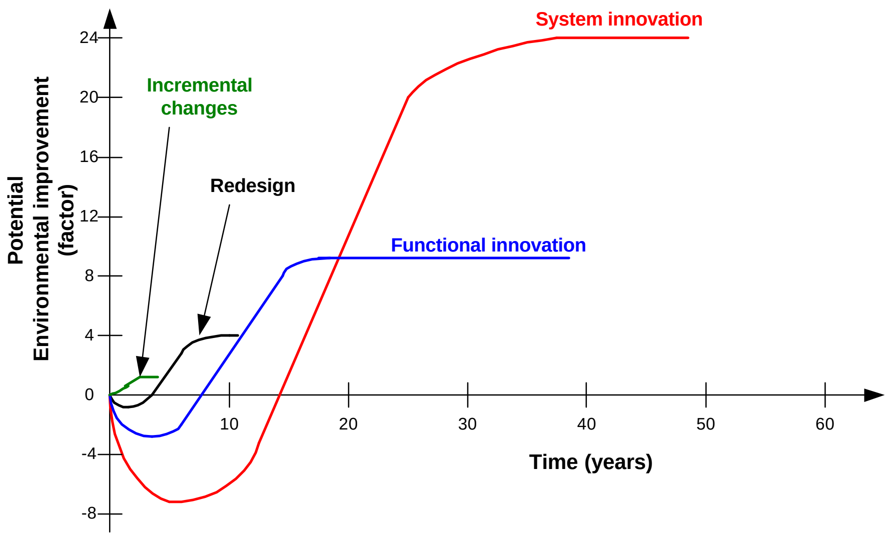

Figure 3: Technological innovation on different levels

Incremental changes in product design may provide immediate improvements (as indicated by not having any initial negative environmental improvement in Figure 3), but may not be sufficient to obtain significant environmental improvements in the long run. This calls for more fundamental changes through system innovation. If Figure 3 depicts a long-term perspective, for example 40 years, we see that total environmental improvements are definitely largest with system innovation, even with severe negative environmental impact during the first years. The challenge is to encourage to long-term thinking and action so that the pro-active investments *are* taken in year 0, and by that remove the infrastructural lock-ins that impede major environmental improvements.

Although the figure shows a reasonable relation between different improvement strategies, it is worth noting that all systems innovations do not necessarily result in total environmental improvements. Building a new airport with improved passenger and freight handling is indeed a system innovation, but it does not necessarily improve environmental conditions from a broader systems perspective. Thus, technological innovation must both have a direction and a rate that is consistent with the aim of sustainability.

4.5 The actors

Understanding how the different actors in society behave and why they behave the way they do, is equally important as understanding the material and energy flows in society. The actors are those who carry out change, and these forces ensure the dynamics in the systems (Forrester 1961). The relative powers of natural forces, structural forces and the forces made by the actors decide the eventual change in the system. Based on the complex picture of the environmental challenge depicted here, there is a *need* for more actors to contribute to the issue raised by industrial ecology. Industry has an important place in this as it has great powers to influence both the environmental properties of a product and consumer patterns in society. Industrial ecology is, however, *not* exclusively for industry and about what industry can do, but rather just as much about what the authorities, academia, media, politicians, consumers, NGOs and industry can do together to meet environmental challenges. The importance of the market as a core actor for implementing change must be stressed. It appears to be rather pointless to rank these actors by degree of importance. As Capra (1996) contends, understanding the *interplay and the interaction* between these actors is the decisive factor if we are to succeed with the aim. Hence, as suggested by Erkman (1997) and Brattebø (1998), every actor must first understand the materials and energy flows and the environmental influence of these flows in a given life cycle system. Second, the actors must understand how they may contribute to reduce the environmental load within and from the defined system.

4.6 Interdisciplinary approaches

The academic sphere is discipline-oriented. Faculties and institutes are organized according to subject areas such as mathematics, chemistry, sociology and economics, to name a few. As shown above, the environmental challenge is very complex with questions relating to economics, consumer behavior, implementation, organization culture, environmental impact and so on, which means that all the subjects mentioned contribute importantly to this issue. When adopting a preventive and systems-oriented approach to the environmental challenge, it is therefore important that industrial ecology is interdisciplinary.[7] The common ground is the interface between eco-efficiency on the micro and macro levels. Hence the importance of having a "separate" discipline as such is reduced. What is important is to ask what each discipline may contribute to this issue.

An interdisciplinary approach implies that a problem is solved through a process whereby participants with different backgrounds are working together and at the same time. There could be interdisciplinary approaches in technological disciplines, for example between chemistry and engineering, and between technological and non-technological disciplines, for example chemistry and political science. In industrial ecology both these two types of interdisciplinary collaboration are needed.

The issue mentioned at the start of this chapter distinguishes particularly between the micro and macro levels. Technologists and business economists are primarily micro oriented, while social scientists, liberal arts researchers and macro-economists are macro oriented. The latter discusses to a greater extent the conditions and basis of what happens, as well as decision processes, implementation and change processes on the macro level. A greater degree of change, as implied by a paradigm shift, assumes a greater need for discussing the basic underpinnings.

Industrial ecology means changing from considering environmental issues as merely local, company-specific, industrial and technological problems caused by industry itself and where solutions largely are end-of-pipe based. Currently environmental challenges are considered to be more or less a societal issue, where consumer patterns and infrastructure are important environmental parameters. This requires interdisciplinary expertise. This is supported by Ehrenfeld (1995) who claims that the designing of sustainable social institutions and framing conditions is just as important as designing new products and processes, and this is what enables sustainable production and consumption.

For academia it is easy to see how interdisciplinary projects may come about. In industry it is harder, as industry works according to a given task, i.e. to produce. What does it mean to industry to work in an interdisciplinary manner? How can a technology-based company include non-technological aspects? How should companies utilize social scientists whose expertise is working on macro issues when the company is micro oriented? How can companies gain increased understanding of eco-efficiency on the macro level and of the importance of their own operations?

[7] The interdisciplinary factor is complicated per se because it is not an established subject field, and hence does not have a standard terminology.

As shown by Hagen et al. (1998), Norwegian companies are now aware that in addition to a technological improvement potential, here related to maximizing profits and minimizing emissions from production plants, there is a large organizational improvement potential where human resources and knowledge, not technology in itself, are essential for the final outcome. This positive trend emerges through a flatter organizational structure with responsibilities allocated to the employees individually.

It may be claimed that the elements of industrial ecology are old knowledge and that the issues have been discussed by various specialists in each field for quite some time. This is largely correct. However, what is new about industrial ecology is that it creates new knowledge through synthesizing and uniting existing knowledge. Synthesizing existing knowledge may mean analyzing how the same issue is regarded by different traditional disciplines. Some of what is new *is* that different disciplines are brought together to illuminate the same issue. The task of industrial ecology is to enhance the development of this new knowledge and implement it in practice. The aim is to unite the two main interests mentioned at the start of this chapter.

4.7 Implementation

Implementation is an important part of industrial ecology (Erkman 1997). As argued by many, it is not the development of technology that is the problem concerning environmental issues, but the implementation and diffusion of it. Even if the aim implies a radical change from current practice, the probability of succeeding is greatest when including the important actors in the process. Industrial ecology seeks to change the way people act, not merely change attitudes. Therefore industry is an important actor. The question is thus how industrial companies and other actors may find ways of influencing the infrastructure and other underpinnings and framing conditions.

Ehrenfeld (1995) describes this when he operationalizes industrial ecology by classifying the main elements of industrial ecology into two main groups: *i) "Critical technologies and infrastructure"* and *ii) "The design of new roles and new rules"*. The first group describes a direct parallel between nature and the industrial system. All the elements here make the industrial system as similar to the natural ecosystem as possible. This is the ideal situation. The second group is the one that distinguishes the industrial society from the ecological one, and is therefore needed if we are to approach such an ideal situation. Contrasting with the natural ecosystem, which is self-regulating, thus needing no external control, the industrial society consists of actors with different interests and needs. Thus, design of new roles and new rules for the actors, roles and rules which are consistent with ecological principles and sustainability, is required.

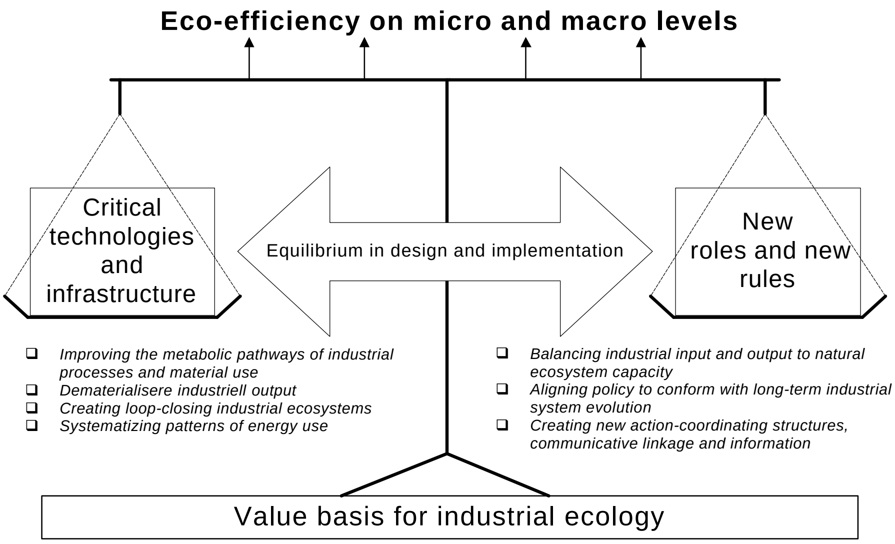

Figure 4: Balance between technological and institutional improvement

Ehrenfeld underlines that a balance is needed between these two groups. This balance is required based on what has been stated previously about the relationship between the micro and macro levels. Designing social institutions and framing conditions which are sustainable is just as important as designing products and production systems. This again emphasizes the importance of an interdisciplinary approach to industrial ecology. This is shown in Figure 4 above.

Another aspect of implementing industrial ecology is how this impacts the actors' organization culture. Figure 5 below shows that industrial ecology must also address more conceptual issues and conditions that *constitute the basis* for more practical and instrumental activity.

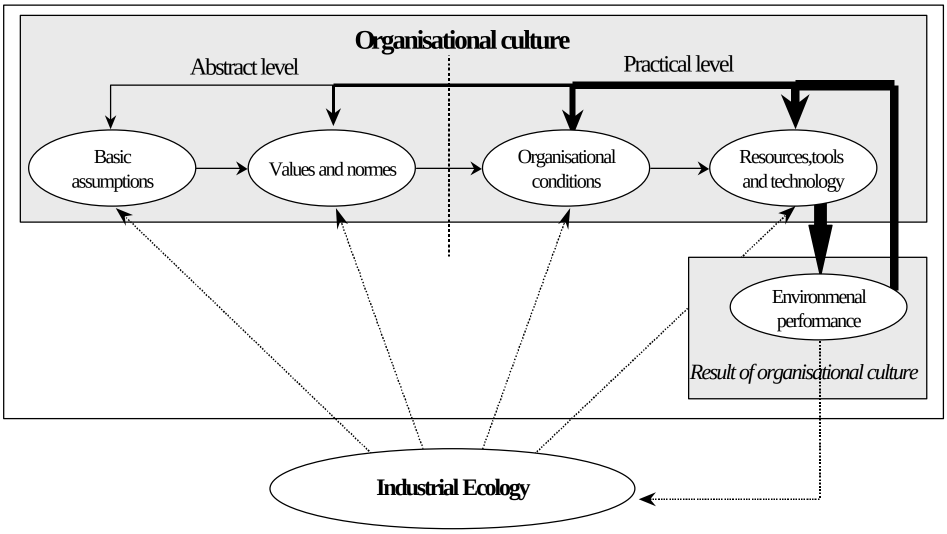

Figure 5: Different analysis levels in a random culture (society/ company/individual)

It is absolutely necessary that industry should have a basic understanding of industrial ecology in its organization culture (abstract/conceptual levels) as this is decisive for what happens on the practical level.

5 CONCLUSION

In this report we have argued that what is new about industrial ecology is the expansion of the system borders within which the actors operate. Bearing this in mind, it is proposed that the most important issue in industrial ecology is *to unite the two main interests; ecological sustainability on the macro level and business- economy profit on the micro level*. Hence, one important element of industrial ecology is how industrial companies interact and collaborate with other actors in the larger systems of which they are a part.

This means that knowledge from different actors and disciplines are needed. This may well be old knowledge that is applied to new issues or new knowledge that is created by blending existing knowledge from various areas. This relates particularly to the understanding of how the interaction among the actors is, as we also attempt to understand the ecological system. As Kiushi (1997) claims, the result of the interaction among the actors gives the system its value, not the value of the individual actors.

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