J. Cleaner Prod. Vol. 5, No. 1-2, pp. 79-86, 1997

0959-6526/97 $17.00 + 0.00
ELSEVIER
PII: S0959-6526(97)00007-3

# Types of industrial ecology: the problem of coordination

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Industrial ecology initiatives have in common the fact that they cross company boundaries, necessitating the coordination of the activities of several economic actors. This article focusses on this coordination problem. Based on organizational sociological concepts, four types of industrial ecology activities are distinguished. Each has its own characteristic coordination problem. From this typology, conclusions are drawn concerning the way in which industrial ecology initiatives can, and should, be stimulated. © 1997 Elsevier Science Ltd.

**Keywords: industrial ecology; organizational sociology; interorganizational relations**

## Introduction

Concepts such as Cleaner Technology and Cleaner Production are instruments in the process of change from Pollution Control to Pollution Prevention. The experience that preventative industrial approaches can generate economic profits and at the same time less pollution is increasingly known. Until now, these concepts have been used within separate firms. In the new concept of Industrial Ecology, the company boundaries passed through are Environment and Utilities and/or Product Development Alliances between firms. This paper reflects on the organizational implications of the developments in industrial ecology from an organizational sociology perspective.

The aim of this article is to discuss the merits of a concept which is receiving increasing attention in the environmental policy community: Industrial Ecology. Attention is focussed on the organizational implications of this perspective. We will argue that the concept of industrial ecology essentially calls for an integrated approach towards the environmental effects of industrial processes, rather than aiming at the reduction of the effects of separate industrial processes. An implication of this perspective is that the organizations responsible for the processes that are subject to this integrated approach should somehow coordinate their activities. Drawing on examples from the Dutch policy domain, we discuss the implications of this interorganizational aspect of industrial ecology.

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In the next section, we will discuss some reservations we have concerning the biological metaphor underlying the industrial ecology concept. Next, we introduce concepts from organizational sociology that are helpful in analyzing one of the central problems of industrial ecology: the problem of coordination. Based on these insights, a typology of different forms of industrial ecology is developed. Each of these forms has its specific coordination problem. In the last two sections we will discuss the implications of our analysis of the coordination problem.

## On the usefulness of biological metaphors

Before taking the industrial ecology concept for granted and analyzing the actual developments that are grouped under this label, it is important to briefly address the adequacy of this metaphor/analogy. In doing so, we will use a much-quoted article from Robert Frosch and Nicholas Gallopoulos[1]. We do not intend to provide a detailed discussion of the merits of this metaphor. However, some points are relevant to our discussion. Most important, as coordination is the central theme of this article, the way in which coordination is thought of in this metaphor is of crucial importance.

The accelerating rate of resource depletion is taken as an incentive for developing innovative concepts which can stimulate (corporate) actors to take the necessary but substantial steps to slow down this rate. The industrial ecology perspective is an example of such a concept. Its basic premise is '...that the industrial system ought to be modified so as to mimic the natural ecosystem in its overall operation'[1] (p. 270). The industrial system is defined as an assemblage of industrial processes, processes which 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 and separately (other definitions of Industrial Ecology are presented in the appendix).

Important is the prescriptive nature of the analogy: '...much could be gained if the industrial system were to mimic the best features of the biological analogue'[1] (p. 271). Why this is desirable remains unclear. Further on, these authors disclose their operationalization: an industrial system should '...approximate *the ideal closed system* or mimic individual biological organisms or specific biological subsystems'[1] (p. 280, emphasis added).

The features of biological ecosystems that should be mimicked by industrial systems are the following[1] (p. 272):

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

Thus, biological ecosystems and individual organisms are used in a prescriptive analogy; functioning *should be* mimicked by industrial ecosystems. In order to be useful in this way, it is important to assess whether the characteristics ascribed to biological ecosystems and organisms are in fact present. Second, if the analogy is to be useful for our purposes, the mechanisms by which these characteristics are achieved and reproduced should provide an insight into the way in which the same characteristics can be achieved in industrial ecosystems.

A biological ecosystem evolves towards a—local—equilibrium via the evolutionary mechanism which operates through the processes of variation, selection and reproduction at the level of organisms. Arriving at an equilibrium state is not necessary, but it often results in biological systems because the process of variation, selection and reproduction (in short, adaptation) runs faster than the environment is changing. It should be noted that an equilibrium state is not necessarily an *optimal* state[3]. As far as individual organisms are concerned, the fact that they do not represent the most efficient adaptation to their environment is argued convincingly by several authors[4,5]. Thus, a biological system evolves from an initial state towards greater efficiency, but this does not mean that it will attain a situation in which the elements are combined in the most efficient way. For our discussion, an additional point is important. With respect to biological ecosystems, the adaptation is the result of an algorithmic process. It is not in any way the result of conscious design[4].

We now come to the question of whether industrial systems in any way resemble biological systems. Over the years, economists have developed ideas about the evolution of industrial systems[6,7]. Certainly, specific changes in industrial systems can be conceptualized as an adaptation to a changing environment. 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.

Finally, an important point, which is mentioned by Frosch and Gallopoulos but which is not addressed, is how large the optimization domain should be. In other words, where should the boundary of the industrial system 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. aluminium) 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[8], the chain of activities related to the life cycle of a product forms the system.

It is not evident that, in such diverse systems as a material cycle and the industrial processes that are performed in a certain geographical region, the same measures are required to establish an industrial ecology.

Rather than dwelling on these shortcomings, we want to stress two points that can be derived from this assessment of the industrial ecology analogy. First, the use of this metaphor rightly emphasizes the fact that industrial processes are interrelated. Reducing the environmental effects of these processes should take these relations as a starting point[9]. This requires the establishment of a system boundary. A second point can be deduced from the basic flaw of the analogy. This is the fact that the adjustment of different processes towards each other, and towards their (natural) environment, does not result from autonomous processes, but can only be achieved by intentional action. Both points will be elaborated upon in the following sections.

## The contribution of organizational sociology

Two developments will be discussed. First, the developing literature on the analysis of interorganizational relations will be briefly addressed. Second, the increasing awareness in society of the importance of managing interorganizational relations is discussed. This last point will provide a starting point for our discussion as it seems to fit with the demands made by the industrial ecology perspective with regard to the solution of environmental problems.

*Interorganizational relations*

Since the middle of the sixties attention has increasingly been paid to interorganizational phenomena; that is, rather than focussing on phenomena and processes *within* organizations, organizational sociologists have directed their attention to phenomena *between* several organizations as well. Whatever its precise definition, industrial ecology can, from a sociological perspective, be conceptualized as an interorganizational phenomenon. Its increasing popularity parallels the development within organizational sociology. While, at first, processes within corporations were the focal point of efforts to reduce the environmental impact of economic activities, the industrial ecology perspective links these processes and is thus concerned with the relations between organizations.

The dominant paradigm in this respect is the *resource dependency perspective*. This approach finds its starting point in the work of Pfeffer and Salancik. In *The External Control of Organizations*[10] they analyze interorganizational relations. Their basic assumption is that these relations are based upon dependency between organizations. This dependency arises from the fact that an organization does not control all the resources necessary for its activities. Thus, a producer of milk is dependent on a producer of milk packaging. Resource dependency can be of two kinds. First, *competitive dependency* exists between organizations that have similar goals. Competitors 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, whatever share is acquired by firm A, cannot be obtained by another firm. Second, 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 in possession of organization B is critical to organization A, while organization A has no comparable resource for organization B under its control. The possibility that a dependency relation is asymmetrical forms the basis of what is considered by Pfeffer and Salancik to be the basic strategic drive for organizations. This drive is based on the desire to be autonomous; in other words, to control the resources critical for the organization. This drive can be translated into the following three basic strategies:

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. Our milk producer could achieve this by installing milk-tanks in supermarkets. Customers could then fill bottles which they bring from home.

This perspective thus bases itself firmly in the drive from organizations towards autonomy. In this respect, it is interesting to note that several authors point to the increasing need perceived by organizations to work together, to cooperate. For instance, Alter and Hage note the increasing occurrence of cooperative relations between organizations[11]. These relations emerge between organizations that stand in a competitive relation to each other as well as in a symbiotic relationship. Several reasons are mentioned for the fact that, despite the basic drive for autonomy, cooperative relations are established. Alter and Hage[11] mention the following factors, some of which are general while others are specific for a (group of) countries (pp. 15–22):

- Efficiency in the production of goods is increasingly directed at quality and flexibility instead of quantity.
- Increasingly, the state is involved in industrial/economic development. This results in partnerships between private and public organizations.
- An increased level of education. This makes individuals better equipped to function in complex institutional environments. Networks of organizations are such institutions.
- The increasing rate of technological change. This makes vertical integration of organizations a suboptimal solution, because it does not provide the flexibility needed to follow this pace.
- The growth of a culture of trust, which is a necessary condition for cooperation between organizations.

*The second industrial divide and interorganizational networks*

The general trend towards increasing cooperation between organizations can be linked with the analysis that a number of economic sociologists have made of developments in the global economy. This analysis has been driven by the wish to explain the decline of American industry, both in absolute terms as well as relative to the success of Japanese corporations. Part of the explanation is the different ways in which economic activities are organized in Japan compared with Western countries on the other. The most striking difference is the network-like structure between business organizations in Japan.

Piore and Sabel have taken this analysis one step further[12]. According to them, these organizational principles, which are still found in some European regions, resemble the way in which economic activities were organized until the end of the nineteenth century. According to several observers, the subsequent development of mass production, and that of big corporations, was a result of the incompatibility of the new production techniques that emerged and the old organizational principles[13]. In other words, autonomous technological change forced organizational change.

Analyzing in detail the historical development, Piore and Sabel add an important point to this account. According to them, at certain branching points, technological change can go in several directions. At such points, political and institutional factors determine which branch will be chosen[12] (p. 39).

One such point occurred at the end of the nineteenth century. Piore and Sabel call this the First Industrial Divide, when craft production was replaced by mass production. According to Piore and Sabel, a similar choice must be made at this moment, because computer technology facilitates different production approaches. They see two alternative trajectories. One is the further development of mass production by multinational corporations. In order to coordinate the activities of these corporations, and to deal with the negative effects of these activities, international institutional arrangements should be developed and strengthened. The International Monetary Fund is an example of such an arrangement. The other trajectory consists of a return to craft production in a new form, which they call *flexible specialization*. This strategy has several facets. One of them is the industrial district. In this geographical region, small corporations with highly skilled workers and flexible—multi-use—equipment, adapt to changes in technology and the market. These corporations are subject to (a set of) coordinating institution(s), which directs this network of organizations towards forms of competition that do not prevent innovation[12] (pp. 265–267). In Europe, regions such as Emilia-Romagna in Italy, and Baden-Württenberg in Germany are examples of such industrial districts.

Other forms of flexible specialization are networks of firms in which one corporation forms the core, while others are attached to it by co-makership relations. An example is the structure of suppliers around Japanese car manufacturers such as Toyota. Toyota engages with a limited number of suppliers in intensive interaction, wherein it develops new products in collaboration with these suppliers.

Examples of both flexible specialization and the multinational development of mass production can be found in, for instance, the USA, Italy and Germany. According to Piore and Sabel, both trajectories are possible, but a choice must be made. It is also possible that Southern countries will develop the mass production trajectory further, whilst advanced capitalist countries of the Northern hemisphere adopt the flexible specialization strategy[12] (pp. 279–280).

Of course, it should be kept in mind that flexible specialization, with its strong linkage between corporations, can take different forms, and is not omnipresent in the world economy[14]. However, this way of organizing economic activities seems to have some characteristics that are interesting from the perspective of industrial ecology. This issue is explored later.

## Establishing new boundaries: types of industrial ecology

As was mentioned above, looking at industrial ecology from an organizational sociology perspective focusses attention on the problem of coordinating the activities of different economic actors. In this section, we will develop our argument that this problem differs for different types of industrial ecology. In the words of the biological metaphor: the choice of the optimization domain influences the character of the resulting coordination problem. It is possible to conceive of the following boundaries:

1. *Product life cycle*: from this perspective, the boundary of an industrial ecosystem is drawn around the economic actors (producers as well as consumers) which are connected with a specific product. Drawing the boundary in this way corresponds with the development of life cycle analysis, a methodology which tries to assess the environmental impact of such systems. Also, several national governments have adopted a product-oriented approach[15]. In The Netherlands, as well as in other European countries, this approach has been adopted by industry as well. The automotive product chain, for instance, has been quite active in this respect. Within this chain, cooperative relations between producers and suppliers, as well as between organizations in the post-consumer phase have developed[16]. A similar development can be seen with respect to PVC-piping systems[17].
2. *Material life cycle*: similar to the product approach, the boundary can also be drawn around actors dealing with a specific material. The examples described by Frosch and Gallopoulos[1]—namely, steel, plastics and platinum—are a good example. Another example is the emergence of the steering group 'PVC and the Environment' in The Netherlands, as well as a similar organization in Germany. Although to a great extent directed at interest articulation, the steering group has acted as the coordination point for a substantial part of this material chain with respect to information gathering on the environmental impact of PVC, as well as a forum in which measures to reduce this impact were developed[17].
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. An actual industrial ecology project in the Rotterdam industrial area ('INES' project) shows starting cooperation in utility sharing and reuse of each other company's waste and effluent between corporations performing production activities in this area. The association 'Europoort/Botlek Interests' of 80 industry members

in the Rotterdam harbor area initiated the INES Project in addition to the support of the development and implementation of environmental care systems within single companies since 1992. While a number of activities of these corporations are totally unrelated, there exist dependency relations between some of them. This is mainly due to the fact that several of these organizations engage in similar activities, such as oil refinery and chemical companies. During the INES project it became increasingly clear that boarding out of 'non-core business' activities, especially in joint approaches of different companies, is attractive for both energy reduction and cost-saving. The involvement of a 'support system' creates optimal synergy in such 'alliance searching' processes[18,19]. Other examples of industrial ecosystems are the Burnside Industrial Park in Halifax (Canada), the Industrial Symbiosis approach in Kalundborg (Denmark) and the Green Region programme in the Storstroem area[20].

4. *Sectoral*: 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. Thus, the elaboration in practice is less related to physical compounds. 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[21,22].

The organizational implications of these different industrial ecology types are different, as the overview in *Table 1* shows. In looking at these possible system boundaries, it seems likely that a system in which ad hoc interrelations are established ('miscellaneous') does not provide a stable basis. Thus, it seems wise not to see such relations as part of a structural industrial ecology strategy.

Drawing the boundary around a sector also seems to be less desirable, because is not directed towards interrelated processes. In other words, industrial ecology has to do with organizations which stand in a symbiotic dependency relationship.

Thus, the criterion for drawing the boundary around an industrial ecosystem is either geographical or based on the product/material chain. It is interesting to note that the advantages of the geographical boundary complement the disadvantages of the product/material chain boundary. Thus, from the perspective of minimizing the ecological impact of economic activities, we should aim at an integrated approach within a region, in which complete, or at least large parts of, product chains are present (including consumption).

Unfortunately, the development in the global economy seems to be much the opposite. Note, for instance, the geographical consequences of the development in the product chain of dairy products. Until the seventies, in The Netherlands the production, packaging and distribution of these products were regionally based. Farmers had organized themselves into regional cooperatives, which dealt with producing consumer products from the milk delivered by the farmers. Supermarkets, which during that period began to take over the distribution of dairy products from milkmen, obtain their dairy products from a regional producer. Due to several factors outside the scope of this paper, dairy producers and supermarkets negotiated contracts on a national scale, thus breaking the regional scope of this product chain. Also, stimulated by an internationalization of the market for dairy products, this led to concentration within the dairy sector. This results in seeking economies of scale by concentrating production in large production centers, with large international distribution networks to bring these products to the customer. Thus, although from a cost perspective this is a move initiated on efficiency motives, it leads to transport, which results in increasing environmental effects from the dairy product chain. Numerous other examples could be mentioned which show a similar development; they all fall under what Piore and Sabel call the international mass production strategy.

## Management of evolution

As mentioned above, an important difference between a biological and an industrial ecosystem is the fact that evolution towards greater efficiency is a spontaneous process, while it needs intentional action in an industrial ecosystem. In other words, achieving industrial ecology objectives requires the management of the relations between the organizations involved. Obviously, this management differs for the types of industrial ecology distinguished above.

As a general starting point, the implications from asymmetrical dependency relations between the organizations involved should be considered. When dependency relations are present in the industrial system under consideration, management of industrial ecology should make use of these relations. For example, in a product chain, a complex web of competitive and symbiotic relations exists between the economic actors involved. Within this network, some actors are more powerful than others. In the product chain of milk packaging in The Netherlands, chains of supermarkets

**Table 1** Types of industrial ecology and their respective organizational implications

| Industrial ecology types | Organizational implications |
|---|---|
| Sector | • Organizations for coordination are available<br>• Competitive dependency precludes extensive cooperation<br>• Limited interrelatedness as aimed for in industrial ecology |
| Product/material, life cycle | • Intermingling of competitive and symbiotic dependency: fewer barriers to cooperation<br>• Coordinative institutions are not available<br>• Cognitive/institutionally complex to determine the right actions |
| Geographical area | • Dependency is not automatically present, and must then be based solely on industrial ecology<br>• Authoritive coordination institutions are available (regional governments and/or industrial organizations)<br>• Separation consumption/production<br>• Top-down or interdependent approach |
| Miscellaneous | • Bottom-up approach<br>• Local optimization<br>• No rationale<br>• Dependency is not automatically present, and must then be based solely on industrial ecology |

determine to a large extent decisions on whether milk is packaged in disposable cartons or in reusable (plastic or glass) bottles. These actors have considerable power over the dairy producers, as their only distribution channel is the supermarket. From an industrial ecology perspective, this is an important observation. It is often argued that such an approach requires the explicit coordination of the actions of all the actors that are part of the product chain. The situation described above is an example of a chain in which influencing the choice made by one actor is sufficient to change the actions of the other members of the product chain[17].

A radically different situation exists with respect to an industrial ecosystem which is defined by a geographical boundary. Such a system comprises organizations that are not automatically dependent on each other; often they are just coincidentally placed next to each other (this is not always the case, of course). When this constellation applies, there is no 'network' on which an industrial ecosystem can be built. Further evidence for the difficulty of this type of industrial ecology comes from the research done by Piore and Sabel. In their analysis of regional networks that are successful, they conclude the following[12] (p. 265): 'The cohesion of the industry [in these regional networks, F.B./L.B.] rests on a more fundamental sense of community, of which the various institutional forms of cooperation are more the result than the cause'.

However, it is possible that a regionally defined ecosystem can be seen as what has been described in the preceding section as an industrial district. In such a case, symbiotic and competitive dependency relations exist, as well as coordinating institutions. These institutions can be regional governments, providing a more hierarchical steering capacity, but they can also assume a more horizontal character, such as the association Europoort/Botlek Interests in the INES Project.

Thus, an initiating organization with sufficient status for the different stakeholders is a critical factor. The association Europoort/Botlek Interests plays this role in the Rotterdam industrial area. Most of the member companies are crude-oil refineries and chemical industries. The companies have been a major focus in the Dutch environmental policies and Europoort/Botlek Interests has developed an intermediary role between the government and industries. Although Europoort/Botlek Interests cannot force better environmental performance of individual companies, arguments from their 'social control' position can stress certain developments. The institutionalized basis of the association has developed into a 'private interest government'[17] (p. 84), which is instrumental in bringing goals and perspectives from the national environmental policy domain to its member companies.

Alternatively, governmental organizations can stimulate cooperation between corporations in product chains. In The Netherlands, the *integrated chain management approach* was adopted as one of the central aims of the National Environmental Policy Program. While it has been difficult to install this approach on a broad scale, several groups of corporations have adopted this perspective in their interest organization. This is an example of a phenomenon which is often encountered in studies of business–government relations[23]. In order to be perceived by government as a respected partner, industry adopts the perspective advocated by the relevant governmental agency. The Dutch chemical industry, for instance, has devoted a lot of energy to promoting the integrated chain management approach[24,25]. Also, as has been described above, several examples can be found of (parts of) product chains that have organized themselves according to this perspective.

## Conclusion: the possibilities of industrial ecology

Our analysis of the coordination problem associated with different types of industrial ecology, and corresponding possibilities of managing these different forms, brings us to the following conclusions.

As was discussed above, industrial ecology demands the coordination of activities of economic actors as well as governmental agencies. It is important to note that *coordination* does not automatically mean *cooperation*. A market, which on one side consists of competing firms, is also a coordinating mechanism, allocating resources (including activities) in a relatively efficient way. As can be seen in the example of milk packaging, depending on the power relations between economic actors, a specific mix of cooperation and competition is called for.

Here we can learn from the literature on the Second Industrial Divide or, as Best calls it, the New Competition[26]. As we have seen, the organizational forms that are part of this development also consist of a mix of cooperation and competition. Rather than expecting the emergence of this mix, Best discusses the important role of governmental agencies and sectoral organizations in bringing about this mix. This point coincides with our discussion of the biological metaphor, in which we amplified the necessity of intentional action in bringing about industrial ecology initiatives. In our examples, we have seen a business association such as Europoort/Botlek Interests as well as the Dutch Environmental Ministry in this role.

While there are parallels between the organization of the New Competition and the coordination necessary for certain types of industrial ecology, it should be stressed that they do not necessarily coincide. At most, consultative relations which emerge in the New Competition can provide a starting point for building 'environmental' co-makership relations[27]. Also, cooperation around the long-term growth of the sector, which is institutionalized in sectoral organizations could be extended to the development of an industrial ecosystem.

In addition, we should qualify our expectations with regard to different types of industrial ecology as distinguished previously. Clearly, in the long run, it is better to deal with ecological effects in the design of products, rather than dealing with waste streams that already exist. In the end, this means that industrial ecology activities which belong to the 'product/material' type deserve priority. The other types, especially 'miscellaneous' and 'geographical area', usually deal with the reuse of waste. From an organizational point of view, they are easier to manage, as the actors are usually located near each other, and coordinating agents already exist. Thus, which is most important in the long run is the most difficult to establish. Moreover, due to their different qualities, it cannot be expected that the 'product/material' type will evolve out of the other types. This leads to the conclusion that actors such as governmental agencies, as well as business associations, are crucial as they are in a position to perform the necessary role of catalysts of industrial ecology initiatives related to products and materials.

A final question to be answered is whether such initiatives will indeed develop. Again, the discussion of the Second Industrial Divide provides a good parallel. The idea of an 'industrial divide' is based on what Piore and Sabel call 'branching points'. By this, they mean moments in the trajectory of technological and institutional change where a choice between different future paths is made. Once this initial choice is made, subsequent choices follow, as expectations, institutions and thus subsequent events are based on this initial choice. In the literature on technological change, this is referred to as *path dependency*[28]. Applied to the possible spread of industrial ecology, the question becomes: Are we at such a point? According to Beck[29], we are precisely at such a point. Due to increasing ecological pressure, fundamental changes in our society are taking place. Based on an extensive study of Dutch chemical industry, Mol argues that industry is indeed restructuring its organizations so as to become more sustainable[30,31]. Thus, it can be argued that actors are increasingly sensitive to incentives to restructure the organization of economic activities.

Since we are at a 'branching point' in relation to the restructuring of the organization of economic activities, it is important to note that such a point consists of a *choice*. As we have argued, this includes a choice between different types of industrial ecology.

## Acknowledgements

We would like to thank Gerard Oostermeijer from the University of Amsterdam, Faculty of Biology, for clarifying several issues concerning biological ecosystems. Needless to say, the responsibility for the points made in this article is completely ours. In addition, we would like to thank two anonymous referees for their inspiring remarks.

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## Appendix

The metabolism of industry is the whole integrated collection of physical processes that convert raw materials and energy, plus labour, into finished products and wastes in a more or less steady-state condition[32].

To manage the earth's resources in such a way as to approach and maintain a global carrying capacity for our species which is both desirable and sustainable over time, given continued evolution of technology and quality of life. The study of what this entails, especially in terms of existing (objective) and desirable (normative) patterns, is industrial ecology[33].

Industrial ecology is a large analytical framework that serves mostly to identify and enumerate the myriad flows of materials and technological artifacts within a web of producers and consumers[34].

An industrial ecosystem is the transformation of the traditional model of industrial activity, in which individual manufacturers take in raw materials and generate products to be sold, plus waste to be disposed of, into a more integrated system in which the consumption of energy and materials is optimized and the effluents of one process serve as the raw material for another process[1].

Industrial ecology involves designing industrial infrastructures as if they were a series of interlocking man-made ecosystems interfacing with the natural global ecosystem. Industrial ecology takes the pattern of the natural environment as a model for solving environmental problems, creating a new paradigm for the industrial system as a process[35].

Industrial ecology applies the principles of natural systems—such as carrying capacity, material flows, resilience, and connectivity—to man-made systems[36].