Quo Vadis Industrial Ecology?
Realigning the Discipline with its Roots

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This paper presents a critical appraisal of developments in research and application in the field of industrial ecology. On its inception around a decade ago, the concept derived great strength from drawing on the metaphor of the natural ecosystem, building on the work of theoretical ecologists, which this paper discusses briefly. Industrial ecologists early on sought to provide advice on problems met in restructuring the socioeconomic system as a whole by using the metaphor of a dynamic natural system comprising producers, consumers and recyclers that can exhibit pioneering and climax phases.

Over the next ten years, as industrial ecology attained more widespread interest as a field with potentially policy-relevant research, a gradual shift away from those aims occurred. The industrial system, only a subset of the socioeconomic system, became the object of observation. The aim of achieving sustainable systems as a whole, it is maintained in this paper, was dropped in favour of analysing individual material flows, and an individualistic perspective supplanted the systemic and holistic perspective. The reasons for and consequences of this development are briefly explored, and suggestions are made for further industrial ecological research that upholds the whole-systems perspective necessary for a sustainable socioeconomic system.

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The past decade has seen the rise of industrial ecology, bringing ideas and practices from ecosystem research into industrial organisation. It has assumed the mantle of a cure to the present system of wasteful economic activity, for industrial ecology seeks to replace the linear input–process–output relationships (turning virgin resources straight into waste and pollution) by cyclical, so-called closed-loop, relationships.

What made this concept so appealing to environmentalists, industry and policy-makers alike? First, there are its seemingly natural origins: industrial systems are compared to natural ecosystems, the only sustainable systems so far. Thus, to industrial ecologists, natural ecosystems are the very systems to understand and to emulate if industrial systems are to be transformed into sustainable systems as well. The simple idea of ‘waste as food’ (Tibbs 1992) mirrors to an extent the complexity of food chains between producers, consumers and recyclers in natural systems. Second, industrial ecology has adopted a language of industrial terminology and has succeeded in pointing out to industry the profit implications of recycling and ‘waste as food’. A growing number of industrial captains and policy-makers in industrial development start to feel as ecologists. Taken as just that, this is a very laudable development (in the past, much of industry’s inertia towards ecological ideas and restructuring could be attributed to an unwillingness to communicate with ecologists).

Has the growing acceptance of ecosystem theory for industry led to the discipline being reconceptualised? It will be argued that this has happened, and that industrial ecology is in need of realignment with its roots if it is to deserve its name.

The natural ecosystem analogy and its use in current research

In all parts of the industrialised world—that is, the triad of North America, Europe and Japan—industrial ecological thinking under various denominations has been slowly proliferating over the past three decades. It was, however, the ‘American school’ in the late 1980s and early 1990s that galvanised research activities and language usage into industrial ecology proper. Ausubel and Wernick from Rockefeller University have produced a research agenda (see Wernick and Ausubel 1997) for industrial ecology, summing up the discipline’s endeavours so far and providing guidelines for future research projects. It comprises three areas of research: the natural ecosystem analogy, derivative concepts and principles, and, last, applications.

The same division in the research field can be found in the work of Vellinga and co-workers (see e.g. Vellinga et al. 1998), who see research in industrial ecology as being organised as follows: ‘intuition and beliefs’ give rise to ‘operational principles and concepts’ that lead to ‘research tools’ (Vellinga et al. 1998: 323f.). Research tools and applications are therefore twice removed from the conceptual level, the ‘metaphor’ of the term ‘industrial ecology’. This distinction between general concepts and applications is not exclusive to industrial ecology: it applies to any research field that endeavours to link theory to practice.

It is in the translation of ‘intuition and beliefs’ into ‘operational principles and concepts’ that a research field is constituted correctly: that is, in the spirit and understanding of those ‘intuitions and beliefs’ or not. Kuhn (1962) called these a ‘paradigm’; Schumpeter (1954) used the more precise term ‘pre-analytic vision’ (for a discussion, see Daly 1992).

The concept of the natural ecosystem analogy as the intuition at the heart of industrial ecology represents a use of metaphor, a term that has come to be associated with vagueness and ambiguity. Therefore, the analogy has not yet been taken seriously in research.
and applications in industrial ecology. In linguistics, a metaphor is understood to be used when one idea is transferred from one field to another. This translation is carried out with an application of precise rules that govern the transfer of concepts from a source domain to a target domain (see Gentner 1982). A metaphor is thus no mere figure of speech, but a highly complex system of understanding that underlies all thought processes (Moore 1982). Thus, an inquiry into the nature of the two domains and the validity of the transfer will be an important part of future industrial ecological research if applications of industrial ecology are to be in line with the intended goal, creating socio-economic structures that behave like natural ones.

The idea that social systems should behave like natural systems stems from the proposition that the socioeconomic system has to be regarded as a subsystem of the ecosystem of the whole biosphere, and thus that is dependent on that biosphere. This proposition came mainly from two different sources. The bio-economist Georgescu-Roegen in his writings of the 1960s onwards likened the traditional image of the economic system as seemingly being sustained by flows of capital but that does not account for resources extracted from stocks and sinks for pollutants to an organism that has a blood circulation system but no digestive tract (see Daly 1995). This insight led a generation later to the recognition of the idea of ‘industrial metabolism’ (Ayres and Simonis 1994) underlying the flow of products, services and money. About the same time as Georgescu-Roegen, the brothers Odum carried out ground-breaking research in systems ecology on the behaviour of ecosystems. Their work has been acknowledged as providing the theoretical basis for industrial ecology. The main ideas from Eugene Odum’s The Strategy of Ecosystem Development (1969) provide a good yardstick against which ideas in industrial ecological development can be evaluated. According to Odum, ecosystems are subject to ecological succession—an orderly and predictable process of community development in an ecosystem. Ecological succession has parallels in the developmental biology of individual organisms and also, according to Odum, in the development of human society. A community in an ecosystem modifies its physical environment by extracting resources and energy. The ensuing ecological succession of species results in a stabilised ecosystem that supports maximum biomass on a unit of available energy, moving from a developmental to a mature state. Incoming energy and nutrients will to an increasing extent be used for maintenance of the system’s complex structures rather than for further physical expansion.

In Socolow et al. 1994, a text published as a definitive guide to the subject area, Thomas Graedel (1994), applying insights from system ecology to the whole of the socioeconomic system, comes to a similar recommendation. He states that the predominantly linear economy (‘type I’ ecology) in the long run will have to live on the influx of solar energy only. Via an intermediate stage (‘type II’, where the system is sustained by extraction of limited resources and disposes of limited waste) it will ultimately conform to a ‘type III’ ecology in which all material flows are cyclical, and the only linear flow is solar energy coming in, being processed and going out as waste heat dissipated into space. This transformation, in Boulding’s (1966) terms, is from a ‘cowboy economy’ to a ‘spaceship economy’, and in Odum’s terms, is from a developmental or pioneering ecosystem to a mature or climactic one.

The ecosystem metaphor in current industrial ecological research

How is this understanding of the ecosystem metaphor translated into operational principles and research tools, and, in parallel, how is the development of the whole economic system as desired by industrial ecologists applied to smaller systems?
Socolow’s (1994) own introductory chapter in Socolow et al. 1994, ‘Six Perspectives from Industrial Ecology’, sets the scene and translates the ecosystem metaphor into practical tools. It is sufficient to look at one of those six perspectives to see how industrial ecologists made the conceptual leap from the large-scale system behaviour of type III ecology to smaller systems and their individual participants: the individual firm and farm as economic agents, Socolow maintains, should take a central position in industrial ecosystem restructuring.

We can see two consequences of this position: first, concentrating on the individual industrial actor or aggregations of such actors, gives preference to only one part of the whole economic system that is made up of manufacturing and service industries and households. The industrial system of manufacturers and service providers becomes the system under observation. But, as it is only a subset of the entire socioeconomic system, this shift in focus in fact separates the two systems, decoupling the whole socioeconomic system from the ability to achieve type III characteristics. Elevating ‘firms and farms’ as central actors negates the integration of producers, consumers and recyclers, as found in all natural systems. According to Socolow’s postulate, it is the set of material and resource flows in production systems that makes up the main body of work in industrial ecology. The ‘eco-industrial parks’ that industrial ecology advocates still only comprise manufacturers and service providers. By instigating research into consumption patterns (Duchin 1992), an attempt was made to address this deficiency. The crucial point remains that now the analysis of production systems has a bolt-on, but still separate, consumption system analysis added to it. An extended systems analysis, reconceptualised as an integrated ecosystem approach, would include flows between production and consumption systems in the fashion of ecological succession. For the economic system this means that the focus of industrial ecological restructuring will have to shift from a technological stance centring on manufacturing to one that includes the notion of sufficiency in production and consumption.¹

In a lecture to the UK Fellowship of Engineering (this group providing possibly quite a good indication as to the target system for industrial ecological restructuring), Robert Frosch made a cautious point: ‘the analogy of the industrial ecosystem concept and the biological ecosystem is not perfect, but much could be gained if the industrial system were to mimic the best features of the biological analogy’ (see Frosch and Gallopoulos 1992). Odum’s research as understood by Graedel gives a clear outline to industrial ecological restructuring: if the economic system is to behave like systems of type III, the similarity of both is not just in some materials recycling. A type III economic system is supposed to resemble a mature ecosystem at the end of ecological succession, cycling all matter in closed loops and sustaining itself solely on the influx of solar energy. Socolow’s position of the centrality of the firm and farm is individualist, conflicting with a focus on the whole of a sustainable system and exposing the contradiction between industrial ecology’s aims and its methods.

The main difference between the economy and an ecosystem of type I² would still be in the fact that, even though the ecosystem has a linear flow-through of matter and energy like the economy, this flow-through does not cause harm to other systems—it provides them with nutrients, as the output is only biomass (and waste heat). Now, although we acknowledge that application of the ecosystem metaphor cannot go so far as to model slavishly individual participants of the economic system on certain species in mature ecosystems, the aim is still to make the whole of the economy display the same behaviour as type III ecosystems.

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¹ In natural ecosystems, this relationship would be akin to supporting maximum biomass by a finite amount of energy with the help of symbiotic relationships between ecosystem participants.

² Such ecosystems do not exist anymore—they are believed to have been present at the very first stages of evolution of life on Earth.
Consequently, it seems that the focus of industrial ecology is wrong. Notwithstanding its vision of a systemic research field, in its application it is individualist (focusing on the producer, as an individual economic actor, and aggregations of producers) and global (relying on the present system of sourcing and trading worldwide), instead of communal and local, the characteristics of natural ecosystems. This position cements the segregated analysis of production and consumption systems, as well as placing a focus on technology-related issues.

A socioeconomic system of type III (or even of type II) will have to address the interface between production and consumption systems. Here, the realm of the individual economic actor is transcended. It is also in the examination of demand that the concept of sufficiency comes to the fore, without which the postulated efficiency increases (such as Factor 4 and similar initiatives; see von Weizsäcker et al. 1997) do not make sense. Even though efficiency of resource use has increased considerably during the past century of industrial activity, aggregate growth in demand for resources has more than cancelled this gain.3

In ecosystem terms, sufficiency can be understood as the ability to live on the income of renewable resources and energy and cycling the whole of the present stock of mineral resources. It does not apply chiefly to the production system, but to the consumption system as well. However, advertising, whose often-forgotten purpose is the creation of demand, reverts some of the consumers’ responsibility back to be borne by producers of economic goods and services.

The individual participants of a mature ecosystem use resources and energy in a sustainable manner because the resource use of the entire system itself is sustainable. Individual participants of an ecosystem have a reason for being only because the ecosystem provides niches for them. This is precisely the point of analysing natural ecosystems in the context of restructuring towards sustainable development—to move away from the individualist perspective of maximising profit and production. In natural ecosystems it would be the bacteria and other pioneering organisms that employ this strategy. These organisms are short-lived and fluctuate between extremes in their total biomass, maximising reproduction in the very short term and declining rapidly after nutrients run out. Human systems, although thought to adhere to profit-maximisation and not looking beyond a short-term or medium-term time-frame, are nevertheless steadily increasing their biomass and rapidly increasing their consumption of resources and energy. They have come to be the dominant actors on the planet, appropriating carrying capacity and photosynthetic production much beyond that of any other species.

Industrial ecology at present attempts to marry up the individualist maximising perspective of mainstream economics with an ecosystem perspective—an inconsistency that will make the concept fail in aiding to bring about sustainable development, becoming the latest victim to turn ‘from green to grey’ (see Welford 1997).

It is acknowledged here that the question of the purpose of demand is probably one of the most challenging to present industrial structures and to the economic agents benefiting from these structures. It is precisely in this area, though, that policy-making for sustainable development has to transcend the realm of the merely technological and must address questions of human needs and wants.

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3 There is a growing number of publications in energy economics that contest the assertion that increasing energy efficiency and materials efficiency will lead to decreasing resource use. Leaving this just to market forces, the opposite happens. See, in particular, two papers by Rees (1995a, 1995b) and also the papers by Herring (1999) and Ayres et al. (1997).
Addressing industrial ecology’s inconsistencies

How can the change from a type I to a type III industrial ecosystem be brought about? Apart from the invisible hand of the market, the visible hand of government regulation is felt to be necessary for going beyond a myopic perspective of NIMBY (‘not in my backyard’) activities. A few proposals (cf. Bey 2001) attempt to make industrial ecology a more inclusive discipline, addressing mostly its narrow focus on the individual firm and its lack of integration of producers and consumers. These proposals, however, are viewed with considerable scepticism by industry, probably for obvious reasons.

The concept of ecological modernisation sees a role for government regulation to integrate economic restructuring by individual economic actors into economic restructuring at the regional level. The approach advocates integrated policy-making, realising that it is economic and industrial activity as a whole that has caused environmental degradation (Gibbs 1996). An ecological tax reform could be seen as an appropriate tool to team up and co-ordinate industrial development with policy-making for the restructuring of the economy. Implementation of such tax reform would place more emphasis, gradually, on whole systems of producers and consumers rather than on individual firms and farms only.

Peck and Tickell (1992) identify five levels of social regulation modes, which Drummond and Marsden (1995) call potential ‘intervention points’ for action. Welford and Starkey (1996) propose regional environmental management systems, analogous to the environmental management systems increasingly used in corporations. That means that industrial ecology needs to examine not only how to minimise one economic actor’s or action’s impact but the impact of the entire system through which the resource flow occurs. A simple example for introducing a systems approach can be found in the problem of using either lead or bismuth in soldering: lead is toxic, but bismuth, although non-toxic, has a greater ecological backpack, as a huge amount of soil and rock has to be displaced in its extraction. A possible solution, instead of reducing the environmental impact of extraction by using lead, would be to recycle bismuth, making further bismuth extraction unnecessary. This would result in an integration of production with consumption systems. Also, logistics would have to be developed to channel the bismuth used in soldering back to the producer and, ultimately, dissipation of bismuth would have to be curtailed.

Owing to industrial ecology’s claim to be the ‘operational approach to sustainability’ (Erkman 1997), the concept has in turn to be compared with aspirations of sustainable development: ‘If a sustainable style of development is to be pursued, then both the level and particularly the structure of demand must be fundamentally changed’ (Lélé 1991). It is the level of demand that industrial ecology at present fails to analyse properly, as we have seen above.

A research project in industrial ecology that did take into account regional demand and production, and the impact of the globalising economy on it, was the ‘Belgium Ecosystem’ (Billen et al. 1983). This work was concerned, too, with charting flows of matter and energy, albeit on the much smaller scale of the Belgian economy. One of the first studies in industrial ecology, before the American school developed, it is much more in line with findings in theoretical and systems ecology. Unfortunately, owing to lack of

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4 Implementation of ecological tax reform can be used to assist and support creation of industrial ecosystems (Bey 2001).

5 It is maintained here that, although industrial ecology aims to study aggregations in the form of ‘industrial ecosystems’, the field’s focus is on the individual firm and individual economic actors. A truly systemic enquiry would first look at the system (at different levels), and only then at individual actors with use of analytical tools from a systems perspective, and not vice versa.
interest in the scientific, political and business communities, the project was not continued.

Michael Shuman’s text, *Going Local: Creating Self-reliant Communities in a Global Age* (1998), makes a detailed proposition of pursuing self-reliance in small communities that is in line with the shifting focus of industrial ecology. Instead of attempting to constrain global business enterprises in their activities, national governments can enable regional or local policy-makers to encourage local enterprise that produces goods and employs people locally, and whose products will be consumed locally. Industrial ecologists will not fail to see the much easier task (as opposed to understanding and managing global aggregate resource flows) of redirecting matter and energy flows into closed loops in such a local system.

Small and medium-sized enterprises (SMEs) that operate locally, rather than global business and multinational corporations, are at the focus of industrial ecological restructuring that takes heed of ecosystem theory. SMEs are not in danger of being sold, as are subsidiaries by their multinational owners. The sale of such subsidiaries is akin to tearing holes not only into the intricate industrial ecological food webs (Clayton *et al.* 1997) but also into the local economy.

Conclusions

Much is to be gained from understanding better the metaphor of the natural ecosystem, and much is to be lost by using it inappropriately. This paper has advocated taking the metaphor seriously, and, by working on the implications of that idea for the economic system, it has suggested we move away from the pick-and-choose approach that industrial ecology seems to have adopted towards the concept that gave the discipline its name.

Iddo Wernick and Jesse Ausubel, who, as representatives of the American school, compiled the research agenda for industrial ecology, acknowledge the responsibility of the field (Wernick and Ausubel 1997): ‘Over the long run, industrial ecology is a good name for the discipline we have in mind only if there is merit to, and insight from, the analogy, not because it connotes an environmentally friendly industry.’

References


Frosch, R., and N. Gallopoulos (1989) ‘Strategies for Manufacturing’, *Scientific American* 261 (special issue on ‘Managing Planet Earth’): 144-52.


